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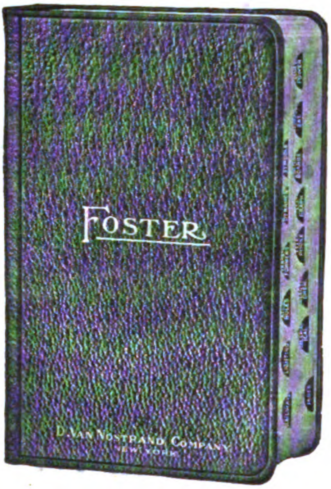

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Twenty-Sixth Annual Convention.

As announced elsewhere, the next convention of the Institute will be held at the Hotel Frontenac, Thousand Islands, N. Y. from Monday, June 28, to Thursday July 1, 1909. There will be seven professional sessions at which thirty-six papers will be presented for discussion. These sessions will probably average more than three hours' duration each, so that a full twenty-four hours will be given over to the consideration of matters of a technical nature. The papers to be presented will cover approximately 600 pages of Institute PROCEEDINGS. Of these papers, one is printed in the May PROCEEDINGS, ten in the June PROCEEDINGS, and nineteen in the July PROCEEDINGS. The remaining six papers will appear in the August PROCEEDINGS. Owing to the large number of papers to be presented and discussed, and the limited time allotted to the professional sessions, it may be necessary to set a time-limit on the presentation of papers and discussions. Allowing for the intermissions of one kind or another that usually attend meetings of this sort, it is not likely that more than thirty minutes can be allowed on the average for each paper and the discussion thereon. As some of the papers are of more than ordinary interest, the time-limit for both paper and discussion may be extended; whenever this is found advisable, the extension will be regulated by the presiding officer at the session at which the paper is presented.

Seattle Section at the Alaska-Yukon-Pacific Exposition

The Seattle Section of the American Institute of Electrical Engineers, in conjunction with the Northwest Electric Light & Power Association, has made arrangements to maintain a booth on the grounds of the Alaska-Yukon Pacific Exposition, for the benefit of visiting electrical men. The booth is located in the northeast corner of Machinery Hall, and bears the emblems of the A.I.E.E. and the N.W.E.L.&P.A. All visiting electrical men are cordially invited to call at this booth, where information regarding electrical development in the northwest will be available. Arrangements have also been made with the Exposition authorities for three electrical days. The dates set aside are September 7, 8 and 9. Institute members who may be in Seattle or vicinity on these dates are urged to attend the Exposition and take part in the meetings of the Section. Such members as may wish to present a paper at one of these Section meetings will be particularly welcome, and they are requested to communicate with the Secretary of the Institute. A special invitation is also extended to Institute members, while in Seattle, to make use of the headquarters of the Seattle Section, in the Central Building.

Announcement of the Twenty-sixth Annual Convention, Frontenac, N. Y., June 28 to July 1, 1909

The Twenty-sixth annual convention of the American Institute of Electrical Engineers will be held at the Hotel Frontenac, Frontenac, Thousand Islands, N. Y., from June 28 to July 1, 1909.

Institute Headquarters

The Institute headquarters during the convention will be at the Hotel Frontenac. On arriving at the hotel, each member should register at the Institute headquarters and obtain an identification badge. The convention sessions will be held in the hotel.

PROGRAM*

Monday, June 28

MORNING SESSION—10 A.M.

1. LOUIS A. FERGUSON, President's Address.
2. A. E. KENNELLY, C. A. WRIGHT AND J. S. VAN BYLEVELT, "The Convection of Heat from Small Copper Wires."
3. E. F. W. ALEXANDERSON, "Alternator for 100,000 Cycles."
4. L. W. CHUBB, "Method of Testing Transformer Core Losses Giving Sine-wave Results on Commercial Circuits."
5. M. G. LLOYD AND J. V. S. FISHER, "Testing of Transformer Steel."

AFTERNOON SESSION—2 P.M.

6. F. CREEDY, "A Sketch of the Theory of the Adjustable-Speed, Single-Phase, Shunt, Induction Motor."
7. E. F. W. ALEXANDERSON, "Repulsion Motor with Variable-Speed, Shunt Characteristics."
8. A. MILLER GRAY, "The Heating of Induction Motors."
9. S. V. CHARTERS, JR., AND W. A. HILLEBRAND, "Reduction in Capacity of Polyphase Motors Due to Unbalancing in Voltage."
10. A. S. LANGSDORF, "The Current Locus of the Single-Phase Induction Motor."
11. H. G. REIST and H. MAXWELL, "Multispeed Induction Motors."

Tuesday, June 29

MORNING SESSION—10 A.M.

12. P. H. Thomas. "Output and Regulation in Long-Distance Lines."
13. P. H. THOMAS, "Calculation of the High-Tension Line."
14. J. B. TAYLOR, "Even Harmonics in Alternating-Current Circuits."
15. J. B. WHITEHEAD, "The Resistance and Reactance of Armored Cables."
16. H. W. FISHER, "Losses, Induced Volts and Amperes in Armor and Lead Cover of Cables."

Tuesday evening at 6 p.m. there will be a dinner and discussion by the Sections Committee and Section Delegates.

EVENING SESSION—8 P.M.

17. W. S. MOODY AND G. FACCIOLI, "Corona Phenomena in Air and Oil and their Relation to Transformer Design."
18. E. E. F. CREIGHTON AND S. D. SPRONG, "Surges on Cable Systems with Aluminum Cell Protection."
19. J. L. WOODBRIDGE, "Split-Pole Converters and Storage-Battery Regulation."

Wednesday, June 30

MORNING SESSION—10 A.M.

20. H C. SPECHT, "Function of Flywheels in Connection with Electrically Operated Rolling Mills."
21. K. A. PAULY, "Alternating-Current Motors versus Direct-Current Motors in Steel Mills"
22. E. W. YEARSLEY, "Rolling Mill Motors."
23. E. FRIEDLANDER, "Electric Driven Rolling Mills."

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* Sequence of papers and the dates assigned are subject to change.

24. B. WILEY, "Power Requirements for Rolling High-Carbon Steel of Small Section."
25. C. T. HENDERSON, "Electrical Control for Rolling-Mill Motors."
26. H. E. WHITE, "Automatic Motor Control."

PARALLEL SESSION—WEDNESDAY 10 A.M.

27. L. W. DOWNES, "Some Considerations in Designing Heavy-Capacity Fuses."
28. C. J. FECHHEIMER, "Comparative Costs of 25-cycle and 60-cycle Alternators."
29. I. E. HANSSEN, "Calculation of Iron Losses in Dynamo Electric Machinery."
30. J. N. DODD, "Auxiliary Poles for Direct-Current Machines."
31. L. T. ROBINSON, "Electric Measurements on Circuits Requiring Current and Potential Transformers."
32. C. A. ADAMS, "Electromotive force Wave-Shape in Alternators."

Thursday, July 1

MORNING SESSION—10 A.M.

33. F. B. JEWETT, "The Modern Telephone Cable."
34. C. A. ADAMS, A. C. LANIER, C. C. POPE, C. O. SCHOOLEY, "Pole-Face Losses."
35. C. R. DOOLEY, "The Education of the Electrical Engineer."
36. C. P. STEINMETZ, "The Value of the Classics in Engineering Education."

Entertainment

The Convention Committee announces the following social functions:

No entertainment has been planned for Monday afternoon, but boating, fishing, golf, croquet, and other outdoor pastimes will be available for those wishing to make use of them.

On Monday evening there will be a reception and dance at the Hotel Frontenac.

On Tuesday afternoon there will be a qualifying round in a handicap golf tournament. The first eight will qualify for the semi-finals. There will also be a women's putting contest, accompanied by first, second, and third prizes.

Tuesday evening there will be a women's bridge tournament.

Wednesday morning there will be a daylight excursion for women through the Thousand Islands on a large steamer. The semi-finals of the golf match and a driving contest will be held Wednesday afternoon.

Wednesday evening there will be a search-light trip of fifty miles among the islands on a large steamer for both men and women.

The finals of the golf tournament will take place Thursday afternoon.

In addition to first, second, and third prizes in the women's putting contest, the following prizes will be given: First prize for men in golf tournament, also runner-up prize in men's golf tournament. There will be prizes for the best net score and the best gross score, as well as first and second prizes in the driving contests.

There will also be first, second, and booby prizes in the women's bridge whist tournament.

Prizes will also be given for the largest fish caught during the convention and also for the largest "catch."

It is proposed to have available a number of launches, which can take small parties around the islands, these parties to be made up by the individuals wishing to take the boat rides. Application may be made to any member of the Convention Committee. Golf will be available for men and women at any time, as the golf links are adjacent to the hotel and are readily accessible. There is a fine nine-hole course. Individuals can obtain guides and rowboats at a minimum charge for fishing at any time. The fishing is excellent.

Transportation

The rate of fare and one-third on the certificate plan which has in previous years been granted by the passenger associations for members and guests attending conventions of the Institute and similar organizations, has recently been increased to a fare and three-fifths, and even this rate is applicable only to a limited territory.

The certificate plan limits the use of the return ticket to three days after the close of the convention and requires each passenger to go and return by the same route. This requirement would prevent many of the Institute members from taking advantage of the reduced rates, as, on account of the many delightful trips that may be taken in going to or leaving the Thousand Islands, a considerable number will desire to go by one route and return by another.

After considering the above facts and other matters relating to transportation, it has been deemed inexpedient to make application for reduced rates on the certificate plan as heretofore. Practically all the transportation companies will have special summer excursion rates to The Thousand Islands in force at the time of the Institute convention. These rates are in general the most advantageous that can be obtained and, in most cases, are very little, if any, in excess of the rates that might be obtained under the certificate plan.

Members should, therefore, consult their local ticket agents regarding routes and rates, preferably several days before they intend to start for the convention.

Hotel Rates

Every member should arrange for his own hotel accommodations. Early application is desirable. Correspondence on this subject should be addressed to the Hotel Frontenac, Frontenac, New York. The management of the hotel has made the following rates, on the American plan, for members and guests attending the convention: $4.00 per day per person for room without bath, $5.00 per day with bath. The rate per day per person is the same whether one or two persons occupy a room.

Sections and Branches

BOSTON SECTION

The May meeting of the Boston Section was held on May 19, with a total attendance of 90, Professor A. E. Kennelly in the chair. The following officers were elected for the year 1909–10: Chairman, D. C. Jackson; vice-chairman, J. W. Corning; secretary and treasurer, A. L. Pearson; executive committee, J. F. Vaughan, N. J. Neall, L. L. Elden, N. B. Ayres, G. W. Palmer. At the conclusion of the business session, Professor E. E. F. Creighton, of Union University, Schenectady, presented a paper on "Demonstrations of Lightning Phenomena."

CLEVELAND SECTION

The annual meeting of the Cleveland Section was held in the electrical building, Case School of Applied Science, on May 17. The result of the election of officers for the ensuing year was as follows: Chairman, H. L. Wallau; secretary, F. M. Hibben; managers, E. P. Hyde, G. E. Miller, B. A. Stowe.

The speaker of the evening was Mr. Clarence Renshaw, of East Pittsburgh, who presented a paper on "The Single-Phase Railway System." The paper treated of generation, distribution, motors, control, etc., and was appreciated by all present. A lengthy discussion followed, many of the leading electric railroad men of Cleveland taking part. Sixty-nine members were present.

FORT WAYNE SECTION

The regular meeting of the Fort Wayne Section was held on May 14, in the rooms of the Fort Wayne Commercial Club. At the business session Chairman E. A. Wagner was appointed official delegate of the Section to the annual convention.

Mr. H. K. English, of the General Electric Company, who has been engaged in the installation of the motor drive of the Gary works of the Indiana Steel Company, presented a paper on "Electricity in Steel Mill Work." The paper was illustrated with lantern slides showing the different adaptations of the electric motor to the work in steel mills. Among other points of interest Mr. English explained the data which had been gained in the way of power required to run blooming mill rolls, etc., by the study of the flywheel effects which was made possible since the use of the electric motor for this purpose. At the conclusion of his paper Mr. English was called upon to explain more fully many of the features of rolling mill work.

ITHACA SECTION

The Ithaca Section held its regular monthly meeting on May 20. There was a total attendance of 110. Mr. W. S. Murray, of the New York, New Haven & Hartford Railroad Company, presented a paper on " The Electrification of the New Haven Railroad."

UNIVERSITY OF KANSAS BRANCH

A banquet was given by the University of Kansas Branch at the Hotel Eldridge, Lawrence, Kansas, on Tuesday evening, May 11. Besides the members of the Branch many of the students taking the electrical engineering course were present. Professor M. E. Rice acted as toastmaster. Among the speakers were: Dean F. O. Marvin, of the university, Messrs. W. J. Squire and T. P. Pinckard, of Kansas City, Mr. J. T. Skinner, of Lawrence, and Messrs. E. J. Thiele, W. A. Caldwell, and H. C. Lauderback. An attractive menu served to enhance the pleasure of the occasion. It was decided to make the banquet an annual event.

The next regular meeting of the Branch was held on May 26. Mr. Carl Dassler gave an account of his graduation thesis work. Mr. Dassler, in connection with Mr. Edmonds, has been working on a device for obtaining a leading current.

LEHIGH UNIVERSITY BRANCH

A large number of members gathered at the final meeting of the Lehigh University Branch held on Tuesday evening, May 18. After the reports of the secretary and treasurer had been read and accepted, the publication of a technical journal by the joint societies of the university was discussed. It was decided that the paper shall be published monthly from October to May inclusive, and shall be known as *The Lehigh Engineer*. The following officers were elected for the ensuing year: President, W. W. Broadbend; vice-president, William Lewis; secretary, H. M. Fry; treasurer, T. O. Beitzel.

MEXICO SECTION

Mr. A. H. Keleher, of New York City, was the guest of the Mexico Section at its meeting held on May 12, 1909, and delivered a lecture on " Scientific Illumination." About 50 prominent members of the electrical profession were present, and Chairman R. F. Hayward presided. Mr. Keleher first defined the difference between light and illumination, speaking also of the physiological effect of light upon the eye. He next made clear the importance of proper distribution and diffusion. A description was given of the modern systems of illumination and light sources, including the arc lamp, incandescent lamp, and gas and acetylene systems. Next the new prismatic reflectors were described. By means of these scientific reflectors which are calculated to the thousandth part of an inch, and which are optical instruments in the same sense as lenses of the telescope and of the camera, all of the light proceeding from the lamp is utilized, the rays of light being redirected to the object which it is desired to illuminate. These reflectors make it possible to concentrate three or four times the quantity of light obtainable from the ordinary lamp and shade, upon a desired plane. Many of the newer and ornamental types of reflectors were shown. In the course of the discussion which followed the lecture, Mr. R. F. Hayward said that while the private illumination of Mexico City is yet rather backward, the public illumination is superior to that of the ordinary city of the United States or Europe, light being used much more liberally in the streets of Mexico than in almost any other place in the world. The first requisite of good illumination, he said, was a sufficient quantity of light.

UNIVERSITY OF MICHIGAN BRANCH

A meeting of this Branch was held on May 20, at which Mr. H. F. Baxter described a test made by himself and several other university students on the Kalamazoo, Battle Creek and Jackson Railway. The talk consisted chiefly of a description of an instrument built by Mr. Baxter with the assistance of Mr. Wiggins and Mr. Appleton for recording pressure, current and speed in the form of curves. Twenty-five members were present.

MONTANA AGRICULTURAL COLLEGE BRANCH

Instead of the regular monthly meeting on May 14, the Branch gave an electrical show in the electrical building. The laboratory and lecture rooms were crowded all afternoon and evening with visitors from Bozeman and others parts of Montana.

The annual meeting was held on May 27. The following officers were elected for the coming year: Chairman C. C. Kennedy; secretary, J. A. Thaler; treasurer, S. A. Williams. The program of the annual convention at Thousand Islands was read and discussed.

NEW HAMPSHIRE COLLEGE BRANCH

The New Hampshire College Branch held its regular meeting on May 24. Mr. C. S. Wendell spoke on the subject of his graduation thesis, " Design and Construction of a High-Tension Testing Transformer." Mr. Wendell described the different parts of the transformer and how they were put together, and illustrated by means of lantern slides the various stages of its construction. In the discussion which followed, Professor Buck explained how the insulating tubes were built up and gave a description of the method employed in insulating or impregnating the coils at the factory. Professor Hewitt spoke of the advances which have been made in the last few years in the construction of high-tension transformers, both for commercial and testing purposes.

OHIO STATE UNIVERSITY BRANCH

The Ohio State University Branch held the last meeting of the school year on May 25, 1909, with Chairman George A. Arnold presiding, and an attendance of 18. An advisory letter was read from Professor Henry H. Norris, of Cornell University. This was followed by a talk by Mr. R. E. Manley, of the Central Union Telephone Company, on " The Method of Operation of Some Modern Telephone Lines."

PITTSFIELD SECTION

Professor Elihu Thomson, of Lynn, Mass., lectured to a large audience at the meeting of the Pittsfield Section held on May 14. His subject was " Thunderstorms and Wireless Transmission." That portion of the lecture concerning thunderstorms dealt largely with the fallacies and false impressions of the general public in regard to lightning phenomena. A popular fallacy is that clouds are charged with electricity similarly to a metallic body, and it was pointed out that this idea is erroneous, because it is the water drops which hold the electricity and discharge the lightning at the point of greatest strain. Thunderstorms occur more frequently in the summer time in the temperate zone because in the winter the clouds bearing water are frozen and the electrical charges in the water are not so great. People are safest in a metallic building during a lightning storm, and those in most danger are people going toward an approaching storm, especially in riding or walking up a hill. It is erroneous to think that it is unsafe to hold any metal such as a knife or needle during a thunder storm. Lightning strikes at any place, and does not seek out a small article like a needle or a knife.

In speaking of the wireless telegraph, Professor Thomson described the instrument used in transmission and gave comparisons and contrasts between its action and that of lightning. The principle of the two is the same. The electricity is stored up as in water drops and when the strain becomes too great there is a discharge of the condensed electricity. The similarity of lightning waves and wireless telegraph waves was demonstrated.

One hundred and thirty members and 24 women were present at the meeting.

PORTLAND SECTION

The Portland Section held its first meeting since its authorization, on May 18, 1909, in the Sherlock Building. Mr. O. P. Guldemeister, of the Portland School of Trades, presented a paper on " Wireless Telegraphy." Mr. Guldemeister explained the principles and demonstrated the actual operation of the apparatus.

SAN FRANCISCO SECTION

At a meeting of the San Francisco Section held on May 28, 1909, an audience of 56 members listened to an interesting paper presented by Mr. Lars Jorgensen, entitled " Impulse and Reaction Turbine Performances with Especial Reference to the Influence of Conduit Friction Loss." The paper was discussed by the engineers of the water-wheel manufacturing companies in San Francisco, and by other members present. Considerable interest was shown in the possibilities of tangential water-wheels working in connection with the draught tube.

The Section recently adopted a set of by-laws. The election of officers for the ensuing year is to take place not later than June 25, 1909.

ST. LOUIS SECTION

A special meeting of the St. Louis Section was held on March 22, to which an invitation was extended to the members of the Engineers' Club of St. Louis. One hundred and five members and guests assembled and enjoyed an interesting address by Professor E. E. F. Creighton, of the Union University, Schenectady, N. Y., on " Lightning and Lightning Phenomena.' Professor Creighton explained the most recent theories as to the cause of thunderstorms and lightning, and described various disturbances which lightning produces, and methods for protection. Demonstrations were given with special apparatus showing effects of the same character as are produced by lightning under certain conditions.

At the meeting held on April 14 Mr. F. H. Blackburn read a paper by Mr. S. E. Doane, of the National Electric Lamp Association, on " Tungsten Lamps." The paper described the various stages of development of the present efficient lamps, also the different sizes, styles, and uses of the lamps. At the conclusion of the paper Mr. Blackburn explained several processes used in the manufacture of filaments.

The annual meeting of the Section was held on May 12. A new executive committee was elected for the year August 1, 1909 to August 1, 1910. The annual report of the secretary was read. The year has been a successful one, and shows increased interest in the work of the Section, the average attendance at meetings being 48 as against 42 for the preceding year. A smoker and social hour followed the meeting, with Chairman Langsdorf as toastmaster.

SCHENECTADY SECTION

The Schenectady Section held its last meeting for the season on Thursday evening, May 13. Four hundred members were present. Mr. M. M. Wood, of Chicago, gave a demonstration of the gyroscope, performing a number of interesting experiments.

The report of the secretary was presented, showing that the work of the Section had been of a high order, and that much interest had been manifested by the membership. During the year nineteen meetings were held, at which the average attendance was 289 members. The membership of the Section now totals 529, of which 259 are Associates of the Institute, and 270 are local members. Of the 259 Associates 18 are located in Albany, 3 in Amsterdam, 6 in Troy, and 232 in Schenectady. The following officers were elected for the season of 1909–10: Honorary Chairman, C. P. Steinmetz; chairman, M. O. Troy; vice-presidents for one year, E. A. Baldwin, A. L. Rohrer, E. E. F. Creighton; vice-presidents for two years, E. B. Merriman, W. I. Slichter, V. E. Goodwin; managers for one year, G. T. Fielding, F. L. Kemp, M. Franklin, O. J. Ferguson; managers for two years, F. H. Gale, T. A. Worcester, J. R. Craighead, G. R. Parker, W. Dalton, R. H. Carlton; treasurer, G. R. Parker; secretary, R. H. Carlton. The various committees are to be appointed at a later date. The report of the treasurer showed the financial standing of the Section to be in good condition, and that the season had closed with all outstanding bills paid and a surplus in the treasury.

SYRACUSE UNIVERSITY BRANCH

The last meeting of this Branch for the season was held on May 13, 1909. Mr. R. H. Newton presented an abstract of the Institute paper on " Conditions Affecting Stability in Electric Lighting Circuits." The Institute papers by Messrs. K. C. Randall and A. B. Reynders, on high-tension apparatus, were presented by N. A. Collins and A. D. Smith.

UNIVERSITY OF TEXAS BRANCH

The University of Texas Branch held its regular meeting on May 14, with 15 members and one visitor present. The program for the evening consisted of a talk by Dr. W. S. Sutton, dean of the school of education at the university, on "The Engineer's Education." He divided engineering education into two principal classes; first, instruction and training in technical phenomena in connection with the profession; secondly other fundamental subjects which do not pertain directly to the profession. At the conclusion of the talk, Mr. Battersby gave a brief discussion on " The Non-synchronous Generator." Mr. H. C. Porter also contributed to the program by an article on " Rate Making."

TOLEDO SECTION

The regular monthly meeting of the Toledo Section was held on Friday evening, June 4, 1909, in the Builders' Exchange. It was voted that no meetings be held during the months of July and August. Mr. John Gilmartin was elected a delegate to represent the Section at the Thousand Islands Convention. Mr. H. L. Wallau, chairman of the Cleveland Section, addressed the meeting. The following men took part in the discussion: Messrs. C. E. Robertson, William Salber, C. B. Cook, John Gilmartin, and George E. Kirk.

WASHINGTON SECTION

The regular monthly meeting of the Washington Section was held on April 24, with a total attendance of 45, Chairman Betts presiding. Mr. Charles W. Stone, of Schenectady, was a guest at this meeting and the speaker of the evening. Mr. Stone gave an interesting talk on " Sub-Station Apparatus."

WORCESTER POLYTECHNIC INSTITUTE BRANCH

At the meeting of the Worcester Polytechnic Branch held on April 30, Mr. A. L. Rohrer gave a lecture on the subject of " Modern Organization of Industrial Works ", which he prefaced with the early history of manufacturing methods. Two points of prime importance are prompt production and accurate costs. The speaker maintained that the organization of any factory must center in these essentials. The organization for production, while important, does not require the degree of attention that should be given to costs, as mistakes in production are sooner and more easily discovered. Different systems of cost keeping were outlined, and the division of costs was explained. The best modern methods in factory organization seem to be very similar to older methods, where each foreman knows all of his men and is thoroughly familiar with the workings of his department. The lecture was illustrated with lantern slides.

On May 14 theses abstracts were given by Messrs. Darrah, Mace and Woodcock. Mr. Darrah told of his thesis work on the application of the electrostatic field, and gave a method of finding the dielectric strength of the electrostatic field without breaking it down. He also described an electrostatic transformer and an electrostatic motor. The talk was illustrated by experiments. Mr. Mace gave a description of the bond-testing apparatus on the Worcester Polytechnic Institute's test car, explaining both the construction and operation. Mr. Woodcock described the different pieces of apparatus used in wireless telegraphy, and gave a short history of their development, concluding with an experimental demonstration with the sending and receiving apparatus in the lecture room. At the conclusion of the lecture Mr. Woodcock invited any who might be interested to accompany him to the receiving station in Boynton Hall where messages were received from South Framingham and Wellfleet.

At this meeting the election of officers took place, and the reports of the secretary and treasurer were read. The following officers were elected: president, Ray H. Taber; vice-president, Otto H. Escholz; secretary-treasurer, Albert A. Nims; executive committee, Ray H. Taber, Albert A. Nims, H. B. Smith, Oliver B. Jacobs, Harold E. Hartwell. It was voted to send the president, Mr. Taber, as a delegate to the 26th annual convention.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before August 1, 1909.

8728 Hofinga, D. H. J., New York City.
8729 Coons, J. W., Berkeley, Cal.
8730 Dean, W. M., Los Angeles, Cal.
8731 McCulloch, J. F., Maquoketa, Ia.
8732 Nissen, C. M., Chicago, Ill.
8733 Crowley, J. W., Baltimore, Md.
8734 Kirkpatrick, C. M., Pittsburg, Pa.
8735 Trennert, R. F., Pinchot, Cal.
8736 Johnson, O. D., Los Angeles, Cal.
8737 Lord, M. C., Vallejo, Cal.
8738 Porter, G. W., San Francisco, Cal.
8739 Woods, R. S., Los Angeles, Cal.
8740 Condon, C. C., Chicago, Ill.
8741 Hannaford, F., Pittsburg, Pa.
8742 Matsukawa, Yuzo, Tokyo, Japan.
8743 Spitzer, Benj., New York City.
8744 Champlin, E. A., Boston. Mass.
8745 Welch, G. W., Boston, Mass.
8746 Heilbrun, R. L., Berlin, Germany.
8747 Morganthaler, P.C., Ft. Wayne, Ind.

Total, 20

Portland Section

At the meeting of the Board of Directors held on May 18, 1909, the organization of a Section was authorized at Portland, Oregon. The Institute members in Portland have been very active during the last three months, and as a result of their efforts the Institute membership in Portland has increased from 15 to over 40. A number of informal meetings have already been held and some interesting papers presented

Personal

Mr. **Foster Veitenheimer**, of the Signal Corps, U. S. Army, has been transferred from Fort Preble, Maine, to Fort H. G. Wright, N. Y.

Mr. **Edwin J. Murphy**, formerly manager of Kelvin & Jas. White of Glasgow, Scotland, is now with the General Electric Company at Schenectady, N. Y.

Mr. **Albert L. Alling** has left New Haven, Conn., and accepted a position as draftsman in the electrical department of the Public Service Corporation of New Jersey.

Mr. **E. H. Bru**, formerly with the Real del Monte Company of Pachuca, Mexico, is now connected with the Butters Divisadero Company, La Union, Salvador, Central America, as installing engineer.

Mr. **Alfred A. Wohlauer**, consulting electrical engineer for light and heat, has removed from his former office to larger quarters at 546 Fifth Avenue, corner of 45th Street, New York City.

Mr. **D. C. Findlay** has severed his connection with C. B. Pride, of Spokane, Washington, and is now associated with Smith, Kerry & Chace, consulting engineers, in their new western office at Calgary, Alberta.

Mr. **W. C. Lancaster**, assistant manager and electrical engineer for the United Engineering and Contracting Company, formerly at 32 East 33rd Street, New York City, is now located at 17 West 42nd Street.

Mr. **William W. Miller** has been promoted from the position of electrical draftsman to assistant expert aide, U. S. Naval Constructor's Office, Newport News, Va. He assumed his new duties March 21, 1909.

Mr. **Oskar Friedrich** has resigned from the Wappler Electric Controller Company of New York, and has taken a position as constructing draftsman with the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

Mr. **Gifford LeClear**, of Densmore & LeClear, consulting mechanical and electrical engineers and mill architects, announces the removal of the firm from 15 Exchange Street, Boston, Mass., to new offices at 88 Broad Street, Boston.

Mr. **A. S. Kalenborn**, formerly with the California Gas & Electric Company, is now in Reno, Nevada, as engineer of operation and construction for the Truckee River General Electric Company, and the Reno Power, Light & Water Company.

Mr. **J. O. Tobey**, formerly division foreman of the San José power division of the Pacific Gas & Electric Company, San José, Cal., has been transferred to the Sacramento division, Sacramento, Cal., where extensive improvements are to be made.

Mr. **G. E. Reiff** has resigned his position as electrical engineer in the engineering department of the Western Electric Company, Chicago, to accept a similar position in the engineering department of the Allis-Chalmers Company, Milwaukee, Wis.

Mr. **Putnam A. Bates** announces his change of address from 42 Broadway to offices at 2 Rector Street, New York City, to which he recently removed in order to avail himself of improved facilities for the needs of his engineering practice.

Mr. **David J. Howell** has removed his engineering office from Huyler Building, 12th and F Streets, N. W., Washington, D. C., where he has been located for the past 12 years, to the Union Trust Building, southwest cor. 15th and H Streets, N. W., Washington.

Mr. Charles Dunckel, electrical and mechanical engineer, has left Ganz and Company of Budapest, Hungary, and has taken a position as general superintendent and engineer of the Szilagyi & Diskant Agricultural Machinery and Engine Manufacturing Company of Miskolc, Hungary.

Mr. George A. Joffe, formerly with the Westinghouse Electric & Manufacturing Company at East Pittsburgh and recently senior student at the Brooklyn Polytechnic Institute, has accepted a position with the Canadian General Electric Company, Peterboro, Ontario, as draftsman.

Mr. Ernst J. Berg, consulting consulting engineer of the General Electric Company, was awarded the degree of D. Sc. at the one hundred and thirteenth commencement exercises at Union University, Schenectady, N. Y. Mr. Berg is also a graduate of the University of Stockholm.

Mr. Robert T. Lozier has become a special representative of the Engineering & Electrical Securities Corporation, a financial company, of which Mr. J. G. White is the president. Mr. Lozier is well fitted for his new connection, having an extensive acquaintance in both the electrical and mechanical fields.

Mr. Kenneth W. Endres, who for the last four and a half years has been with the engineering department of the American Telephone and Telegraph Company in Boston and New York, has resigned from that company to accept a position in the Pennsylvania sales office of the Electric Storage Battery Company, Philadelphia.

Mr. Kengo Makino has recently been appointed professor of electrical engineering, University of Waseda, Tokyo, Japan, where electrical and mechanical courses are to be established in the coming autumn. Mr. Makino will visit various European countries, and will reach Japan in the latter part of August.

Mr. Hartwell Jalonick has withdrawn from the Dallas, Texas office of the General Electric Company, and established an engineering office in El Paso, Texas, where he will conduct a consulting mechanical and electrical engineering business, with particular attention to interests in Texas, Arizona, New Mexico, and Mexico.

Mr. J. R. Bibbins, who since 1902 has been associated with the Westinghouse interests at Pittsburgh, Pa., will after June 18 become associated in the work of the Public Service Commission of New York, as assistant to Mr. B. J. Arnold, consulting engineer and director of appraisals. His new offices will be in the Tribune Building, City Hall Square, New York City.

Mr. Horatio A. Foster has been transferred from the valuation department of the Public Service Commission, First District, New York City, to Detroit, Mich., to take charge of the appraisal of the properties of the Detroit United Railways for Mr. Bion J. Arnold, with whom he has been associated in the valuation of the properties of the New York City railways.

Mr. Harold L. Barnholdt, for several years with the engineering staff of the Stanley Electric Manufacturing Company and its successors, the General Electric Company, Pittsfield, Mass., has terminated his connection with this company and accepted a position as engineer in the industrial division of the Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa.

Professor L. A. Herdt, who for the past ten years has been connected with the electrical department of McGill University, Montreal, Canada, has been appointed head of that department. Professor Herdt, who is a graduate of McGill University, also studied in Europe—at the Laboratoire Central d'Electricite, Paris, and at the Institute Electrotechnique, Montefiore, Liege, Belgium.

Upon the joint recommendation of the Ministers of Foreign Affairs and of Communications, his Imperial Majesty, the Emperor of Japan, has bestowed on Mr. John J. Carty, a vice-president of the Institute, the Order of the Rising Sun, in recognition of the distinguished engineering services which he has rendered to the Japanese government. The insignia of the order were presented by Baron K. Takahira, the Japanese ambassador at Washington.

Mr. C. G. Young, who until last February was associated with J. G. White & Company, of New York, is visiting Japan on business. Mr. Young was with the J. G. White Company for 17 years, and is now in business for himself, with offices at 60 Wall Street, New York City. Mr. Young's financial and engineering operations have brought him in nearly every quarter of the globe. This is his third trip around the world.

Mr. G. Monrath, consulting engineer for 10 years with the Grace & Hyde Company, has been instrumental in organizing the American Development & Securities Company, with offices and show-room at 35-39 West 33rd Street. The company has been organized for the purpose of developing such projects of natural resources in the northwestern states as may claim their attention. Mr. Monrath's position is that of treasurer and general manager.

Mr. F. F. Kinney has resigned his position as acting head of the testing department of the Commonwealth Edison Company of Chicago, to become general manager of the Minerallac Electric Company, which has recently been organized to take over the business of the Minerallac Company and the Chicago Electric Meter Company. Mr. Kinney invented and developed a system of printing wattmeters to carry out the Chicago method of selling electricity for industrial power.

Mr. R. A. L. Snyder and **Mr. S. P. Grace**, both of Pittsburgh, Pa., are the joint inventors of the "telmegaphone", a device by means of which an assembly may be addressed by the speaker at a distance, through an ordinary telephone receiver. It has a phonograph horn, and the mechanical parts of a greatly enlarged telephone. A test of the instrument was recently made between New York and Pittsburgh, with very satisfactory results. The conversation from the New York end was as audible in Pittsburgh as if carried on in the same room.

Mr. J. Allan Smith, who for the last 10 years has been associated with the Fort Wayne and the General Electric Companies, has accepted the position of general manager of the United States Light & Heating Company, a corporation which has absorbed the Bliss Electric Car Lighting Company of Milwaukee, the National Battery Company of Buffalo, and the United States Light & Heating Company of New Jersey. The company will furnish all classes of storage-batteries, and many types of generators, regulators and other equipment for electric car lighting. The general office is at 30 Church Street, New York City.

Mr. Bernard Elshoff has severed his connection as superintendent of the electrical department of Allis-Chalmers Company, Milwaukee, Wis. Mr. Elshoff joined The Bullock Electric Manufacturing Company of Cincinnati

14 years ago, in charge of the winding department. Later he was advanced to assistant general superintendent of the company. In 1907 he became superintendent of the electrical department of Allis-Chalmers Company, in which capacity he organized that company's electrical manufacturing department in Milwaukee.

U. N. BETHELL of New York, president of the New York and New Jersey Telephone Company, the Bell Telephone Company of Pennsylvania and the Central New York Telephone and Telegraph Company, has been advised by Baron Takahira, the Japanese Ambassador at Washington, that the Emperor of Japan has conferred upon him the Imperial Order of the Rising Sun, in recognition of valuable assistance given the government engineers of Japan, who have been sent to this country within the last few years to investigate the telephone systems and the management of large industrial enterprises.

PROFESSOR HENRY S. CARHART, head of the department of physics, University of Michigan, will retire on October 1, 1909, after 23 years of active service. Professor Carhart was graduated from the Wesleyan University, Middletown, Conn., in 1872, with the degrees of B.A. and M.A. He subsequently studied for one year at Yale University. In 1873 he was appointed professor of physics in the Northwestern University, which post he retained until 1886. From 1886 to the present time he has been associated with the University of Michigan. He established there the electrical engineering course and had the directing of it. Professor Carhart represented the Institute in the joint discussion with the Institution of Electrical Engineers at the St. Louis Electrical Congress in 1904. He was also a leading delegate at the Paris Exposition of Electricity in 1881, and the Chicago International Congress and World's Columbian Exposition in 1893. In 1892 he patented the standard cell known as the Carhart-Clark Cell, and more recently devised a form of the normal Clark Cell. Besides contributing to many scientific and technical journals, Professor Carhart published " Primary Batteries " in 1891, " Elements of Physics ", in connection with H. N. Chute, in 1892, " University Physics ", Part I, in 1894, " Electrical Measurements ", in connection with George W. Patterson, Jr., in 1895, " University Physics ", Part II, in 1896.

Obituary

CHARLES LUMAN BUCKINGHAM, a charter member of the Institute, died at his home at 104 East Eighty-first Street, New York City, on May 31. He was born at Berlin Heights, Ohio, on October 14, 1852, and was educated at the University of Michigan and the Columbian University. He made a specialty of patent law, and was counsel for the Western Union Telegraph Company in many of its important patent suits early in the '80s. He was also counsel for the General Electric Company, the Westinghouse Electric and Manufacturing Company, the Edison companies, and many others. He became a charter member of the Institute on April 15, 1884, when its first meeting was held, and the following year he was elected a manager, serving one term on the Council, 1885–8. He was one of five who purchased for donation to the library of the A. I. E. E., a valuable classified collection of all the United States electrical patents issued down to 1891, numbering more than one hundred volumes. He was also a member of the Ohio Society, the Metropolitan Club of Washington, and the University Club. The funeral services were held on Thursday evening, June 3, in the Madison Avenue Reformed Church, Fifty-seventh Street, New York City, and the interment took place at Woodlawn Cemetery on June 4. One of his sons, Henry H. Buckingham, is a student at Cornell University.

Mr. Tomokichi Hirokawa, late chief engineer of the Kyoto Electric Light Company, Kyoto, Japan, died on February 10, 1909. Mr. Hirokawa was born at Imabari, Japan, on December 2, 1871. After a liberal education at Doshisha College, Kyoto, Japan, he came to the United States and entered the New Hampshire College, Durham, N. H., graduating from that college in 1898, with the degree of B.S. He then took the electrical engineering course at the Massachusetts Institute of Technology, and was graduated in 1900. After his graduation he worked for a few months at the General Electric Company's works at Lynn, Mass., and later for the Boston Elevated Railway Company. Early in 1901 he went back to Japan, where he accepted the appointment of instructor in physics and mathematics at the Doshisha College, Kyoto. He resigned the appointment during the latter part of 1902 and accepted the position of chief engineer of the Kyoto Electric Light Company. He was elected an Associate of the Institute on December 18, 1903.

Mr. Julius R. Jacobson, an Associate of the Institute, of Syracuse, New York, was drowned in a motor boat accident in Brazil on May 2, 1909. Mr. Jacobson was one of a party of 15 persons, and six other members of the party lost their lives. Mr. Jacobson has been in Brazil for some years, and was superintendent of the Sao Paulo Tramway, Light & Power Company, Ltd., Sao Paulo, Brazil. He was also a special representative of the General Electric Company.

He became an Associate of the Institute on October 24, 1902. His parents, two brothers, and one sister, all of Syracuse, N. Y., survive him. The body will be brought to that city for burial.

Fred Charles Almond, of Clear Lake, South Dakota, died at his home on March 12, 1909. He was born in Deuel County, South Dakota, on January 23, 1881. After his preliminary education in the public schools of Clear Lake, he spent two years in the South Dakota Preparatory School, and in 1898 entered the State College of Mechanic Arts, graduating in the spring of 1903 with the degree of B.S., M.E. The same year he entered the University of Wisconsin, from which institution he was graduated in 1904 with the degree of B.S., E.E. He commenced his business career in the summer of 1904 as general repairman for the Citizens' Electric Light and Telephone Company, of Clear Lake, S. D. From the fall of 1904 he held successively, in various companies, the positions of draughtsman, shop inspector, assistant cable engineer, switchboard engineer, and at the time of his death was chief engineer of the North Dakota Independent Telephone Company of Fargo, N. D. In the last named position he had personal charge of extensive and important construction work. He became an Associate of the Institute on April, 26, 1907.

Ralph Scott, of the Scott Electrical Company, Newark, N. J., died on April 25, 1909, while under the influence of ether preceding an operation for appendicitis. Mr. Scott was elected an Associate of the Institute on March 12, 1909. He was born in Bradford, Yorkshire, England, on November 5, 1882, coming to this country when a child. On his graduation from the Wilkesbarre, Pa. high school he took up the electrical power and lighting and electrical engineering courses of the International Correspondence Schools. Although only 26 years of age at the time of his death, Mr. Scott had made his mark in the scientific world as an inventor, having been granted patents on more than 40 electrical inventions. He was also the author of a number of electrical works, and a contributor to some of the technical journals. Among his works are: "Automatic

Block Signals", pamphlet on electrical engineering, 30 correspondence school text-books, and about 200 articles on electrical subjects which were published in the technical press of America and Europe during the last 8 years. His work will be carried on under the direction of his father, who survives him.

ALMON H. DEMRICK, electrician, U. S. Reclamation Service, Salt River Project, and an Associate of the Institute, was drowned on May 3, in a 600-foot sluicing tunnel which had been cut through a mountain at one end of the Roosevelt, Arizona, storage reservoir. One of his associates with him at the time was swept through the tunnel with him, but emerged without serious injury into the river into which the sluice empties. Mr. Demrick was born at Roseville, Michigan on September 6, 1868. He was graduated from the engineering department of the University of Michigan with the degree of B. S., E. E. in 1894. After his graduation he engaged as assistant engineer with Field and Hinchman, of Detroit, Mich. In 1897 he entered into business under the firm name of A. H. Demrick & Company, contracting electrical work, Detroit, Mich. He became electrician in the U. S. Reclamation Service in 1904, and at the time of his death had charge of all the electrical and power construction in connection with the Salt River Valley reclamation project. He was elected an Associate of the Institute on February 14, 1908.

Accessions to the Library

The following accessions have been made to the Library of the Institute since the last acknowledgment:

American Electrical Directory 1889. Fort Wayne, Ind., 1889. (Gift of McGraw Publishing Co.)

American Mining Congress. Report of Proceedings 11th Annual Session, 1908. Denver, 1909. (Gift.)

American Street Railway Decisions. Volumn I. Edited by C. A. Richardson and A. J. Hook. Brooklyn, American Street Railway Association, 1890. Purchase.

American Street Railway Decisions. Volume II. Edited by C. A. Richardson and A. J. Hook, Brooklyn, 1894. Purchase.

Annuaire de l'Electricité et des Industries électriques. By Camille Rousset. 1909. Paris, 1909. $4.50.

Application of Syracuse, Geneva and Corning Railway Company and Fall Brook Railway Company for Permission to Consolidate, etc.—Opinion of the Commission. New York, 1909. (Gift State of New York Public Service Commission. Second District.)

Application of the Buffalo, Rochester and Eastern Railroad Company for a Certificate of Public Convenience and a Necessity under section 559 of the Railroad Law, and for permission to commence construction and exercise franchises under section 53 of the Public Service Commissions Law.—Opinion of the Commission. 1909. New York (Gift of New York State Public Service Commission Second District.)

Application of the New York and Ontario Power Company for Leave to Issue Stock and Bonds—Opinion of the Commission. New York, 1909. (Gift of New York State Public Service Commission, Second District.)

Application of the New York Central and Hudson River Railroad Company for Leave to Purchase the stock of the Spuyten Duyvil and Port Morris Railroad Company—Opinion of the Commission. No place, 1909. (Gift of New York State Public Service Commission. Second District.)

Association Francaise pour l'Advancement des Sciences. 1900, 1901, part 2, 1902–1907. 13 volumes. Paris, 1900–1908. Purchase.

Catalogue Général Officiel, Paris Exposition Internationale Universelle de 1900). Lille, 1900. Purchase.

Catalogue of the Wheeler Gift of Books, Pamphlets and Periodicals in the Library of the American Institute of Electrical Engineers. Edited by W. D. Weaver, with introduction, descriptive and critical notes by Brother Potamian. Volumes 1–3 interleaved. New York, 1909. (Gift of W. D. Weaver.)

City of New York—Board of City Magistrates. Annual Report 1908. New York, J. W. Pratt Company, 1909. (Gift.)

Complaint of the City of Elmira Against Erie Railroad Company—Opinion of the Commission. No place, 1909. (Gift of New York State Public Service Commission. Second District.)

Complaint of the Residents of Lakeville against Erie Railroad Company as to Operation of Cars on its Coensus Lake Branch during the Winter Months—Opinion of Commission. No place, 1909. (Gift New York State Public Service Commission. Second District.)

Electrical Trades' Directory and Handbook for 1903. London, "The Electrician", 1903. (Gift of McGraw Publishing Company.)

Engineers' Club of Central Pennsylvania. Journal. Volume I, numbers 2–3. Harrisburg, 1909. (Gift of Engineers' Club of Central Pennsylvania.)

L'Exposition Universelle, Paris, 1889. Paris, 1890. Purchase.

Formulaire de l'électricien et du mécanicien. By E. Hospitalier. 23d edition by Gaston Roux. Paris, 1909. $3.00.

Gas and Electric Light Commissioners of the Commonwealth of Massachusetts Annual Report. 22d. and 24th Boston, Wright & Potter Printing Co., 1909. (Gift of Commissioners.)

L'Industrie des Tramways et Chemins de Fer. Year 1, numbers 1–5, 7--8, 10–12; year 2, numbers 1–5, 7. Paris, 1907–1908. (Gift.)

Institution of Post-Office Electrical Engineers. Catalogue of Books in the Central Library, 1909. London, 1909. (Exchange.)

International Catalogue of Scientific Literature. 6th Annual Issue. D-Chemistry. London, 1909. Gift

International Catalogue of Scientific Literature. 7th annual issue. A-Mathematics. London, 1909. Gift.

Iowa Electrical Association. Proceedings of the Annual Convention 8th. Des Moines, 1908. (Exchange.)

Isolated Plant. Volume 1-date. New York, 1909-date. (Gift.)

Legal Papers—Street Railway Law. Brooklyn, American Street Railway Association, 1884–1891. Purchase.

Minutes of the Board of Commissioners of Electrical Subways in the City of New York. Volumes 1–2. New York, J. W. Pratt Co., 1904. (Gift of H. S. Wynkoop.)

New Amsterdam Gas Company Preliminary Abstract of Report for the half-year ended December 31, 1907. (Gift of New York State Public Service Commission for the First District.)

Die Normalen Eigenschaften elektrischer Maschinen. Von Rudolf Goldschmidt. Berlin, J. Springer, 1909. (Gift of Publisher.)

CONTENTS.—I.—Gleichstrommaschinen. II.—Rotierende Unformer. III.—Synchrone Wechselstrommaschinen, Wechselstromgeneratoren, Synchronmotoren. IV.—Asynchronmotoren (Induktionsmotoren). V.—Einphasenmotoren mit Kommutator. VI.—Transformatoren. VII.—Der Wirkungsgrad der elektrischen Maschinen bei Unter-und Uberlastung. VIII.—Der Leistungs faktor (cos ϕ) von Induktionsmotoren bei Unter-und Uberlastung. IX.—Der aussetzende (intermittierende oder Kran-) Betrieb.

Official Catalogue National Electric Exposition May 1896. New York, 1896. Purchase.

Official Guide to the World's Columbian Exposition. Chicago, Columbian Guide Company, 1893. Purchase.

Pitting of Iron Particularly Pipe . . . Its Causes and Possible Preventives.

By F. P. Siebel. No place, no date. (Gift of author.)

Popular Science Monthly. Volumes 58–60. New York, McClure, Phillips and Co., 1190–1902. Purchase. Purchase.

Preliminary Abstracts of Reports for the year ended June 30, 1908 of the Long Island Electric Railway Company New York and Long Island Traction Company Ocean Electric Railway Company. No place, no date. (Gift of New York State Public Service Commission for the First District.)

Proceedings of a Conference of Governors in the White House, Washington, D. C., May 13-15, 1908. Edited under the direction of N. C. Blanchard, Chairman, J. F. Fort, J. C. Cutler, J. O. Davidson, M. F. Ansel, the Committee of Governors, by W. J. McGee. Washington, U. S. Government, 1909. (Gift).

Publishers' Weekly. Volumes 57-63. New York, 1900–1903. (Gift of McGraw Publishing Company.)

Questions and Answers about Electrical Apparatus. Edition 2, revised and enlarged. By W. B. Clayton and J. W. Craig. West Lynn, 1909. (Gift of authors.)

CONTENTS.—Direct Current Motors.—Induction Motors.—Constant Potential Transformers.—Constant Current Transformers.—Mercury Arc Rectifiers.—Incandescent Lamps.—Arc Lamps.—Meters and Instruments.—Steam Turbo-Generators.—Wire Table.

Relation des Expériences. Volumes 1–3. By V. Regnault. Paris, D. Fréres, 1847, 1862, 1870. (Purchase.)

Report of Examiners of Sections XIV–XVI—Batteries of the International Electrical Exhibition. Philadelphia, 1885. (Gift of McGraw Publishing Company.)

Report to the Governor of the Advisory Board of Consulting Engineers of New York State upon its work relating to the Barge Canal from January 1, 1907 to January 1, 1908. Albany, J. B. Lyon Co., 1908. (Gift.)

Results of Observations Made at the Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland. 1901–1904. Washington, U. S., Government 1909. (Gift.)

Results of Observations made at the Coast and Geodetic Survey Magnetic Observatory at Sitka, Alaska, 1902–1904. By D. L. Hazard. Washington, U. S. Government, 1909. (Gift.)

Results of Observations made at the Coast and Geodetic Survey Magnetic Observatory at Vieques, Porto Rico, 1903–1904. By. D L. Hazard. Washington, U. S. Government, 1909. (Gift.)

Universal Electrical Directory, 1907. London, A. Alabaster, 1907. Purchase.

University of Illinois-Engineering Experiment Station. Bulletin. Volume III, Nos. 18–26. Urbana, 1908. (Gift.)

Utah Society of Engineers, Annual Report. 2d. Salt Lake City, 1909. (Gift.)

Westinghouse Electric Street Car Equipments. By F. L. Hutchinson and L. A. Phillips. East Pittsburg, 1896. Purchase.

Wireless Telegraphy and Wireless Telephony. By A. E. Kennelly. New York, Moffat, Yard & Company, 1909. Purchase.

Trade Catalogues.

Crocker-Wheeler Co., Ampere, N. J.

Bulletin No. 111, March, 1909. Electrical Equipment of Peter Doelger's Brewery, showing electrical machinery, generating plant, and electrified shop of the brewery.

Bulletin No. 112, March, 1909. Exhaust Fans. Cut, description and detail drawing of a 36 in. exhaust fan.

Bulletin No. 113, April, 1909. Large Direct Current Motors for direct connection. Cuts and description of detail construction of a 250 h.p. 230 volt, 125 rev. per min. motor with base and bearings.

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Sections and Branches—Directory.

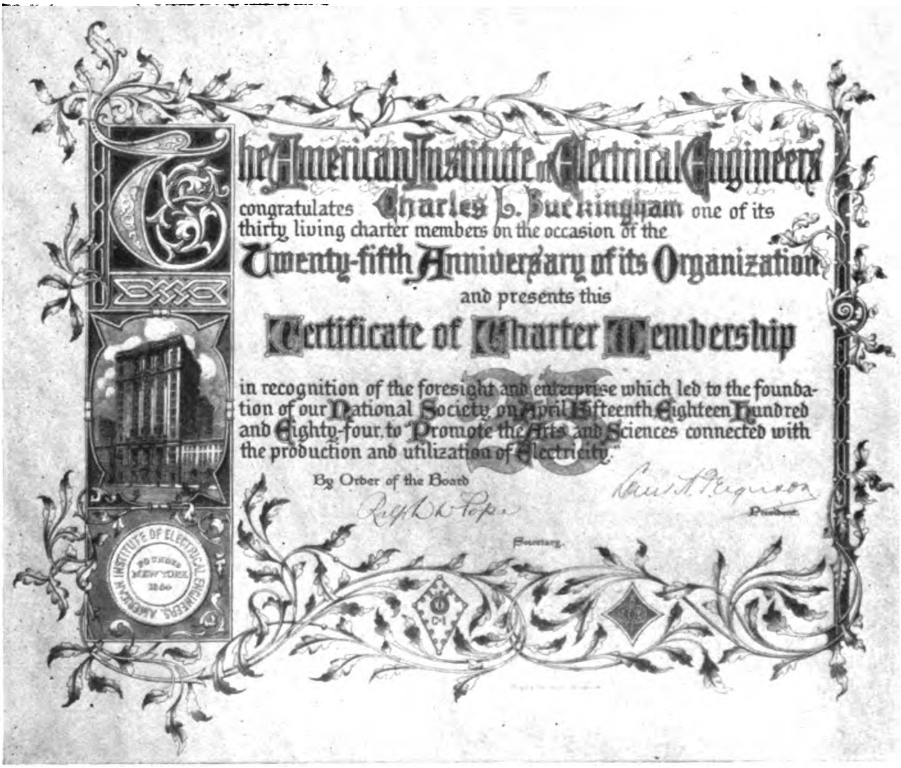
SECTIONS	Organization authorized by Board of Directors	Chairman	Secretary
Atlanta	Jan. 19, '04	W. R. Collier	E. P. Peck, Box 52, Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	D. C. Jackson	A. L. Pearson, 93 Federal St., Boston, Mass.
Chicago	1893	W. L. Abbott	J. G. Wray, 203 Washington St., Chicago, Ill.
Cleveland	Sept. 27, '07	H. L. Wallau	F. M. Hibben, 1549 Winton Ave., Cleveland, O.
Columbus	Dec. 20, '03	R. J. Feather	H. L. Bachman, 1070 E. Fulton St., Columbus, O.
Fort Wayne	Aug. 14, '08	E. A. Wagner	J. V. Hunter, 506 W. Jefferson St., Ft. Wayne, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	B. C. Dennison, Cornell Univ., Ithaca, N. Y.
Los Angeles	May 19, '08	C. W. Koiner	J. E. MacDonald, 444 P. E. Bldg., Los Angeles, Cal.
Madison	Jan. 8, '09	C. E. Carter	J. W. Shuster, Univ. of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07	R. F. Hayward	F. D. Nims, Mex. Lt. & Pr. Co., Mexico, Mex.
Minnesota	Apr. 7, '02	Barry Dibble	J. C. Vincent, 1313 6th St., S. E., Minneapolis, Minn.
Norfolk	Mar. 13, '08	D. G. Stanbrough	R. R. Grant, P. O. Box 254, Norfolk, Va.
Philadelphia	Feb. 18, '03	Paul Spencer	H. F. Sanville, 1708 Sansom St., Phila., Pa.
Pittsburg	Oct. 13, '02	W. Edgar Reed	B. P. Rowe, 911 Ramsey Ave., Wilkinsburg, Pa.
Portland, Ore	May 18, '09	O. B. Caldwell	L. B. Cramer, 67 N. 20th St., Portland, Ore.
Pittsfield	Mar. 25, '04	W. A. Hall	H. W. Tobey, General Electric Co., Pittsfield, Mass.
San Francisco	Dec. 23, '04	C. W. Burkett	S. J. Lisberger, 925 Fanklin St., San Francisco, Cal.
Schenectady	Jan. 26, '03	M. O. Troy	R. H. Carlton, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	J. H. Harisberger	Geo. H. Moore, Rialto Court, Boylston Ave., Seattle, Wash.
St. Louis	Jan. 14, '03	A. S. Langsdorf	H. I. Finch, 5217 Morgan St, St. Louis, Mo,
Toledo	June 3, '07	C. R. McKay	Geo. E. Kirk, 1614 The Nicholas, Toledo, O.
Toronto	Sept. 30, '03	W. A. Bucke	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana	Nov. 25, '02	E. B. Paine	E. I. Wenger, 911 W. California St., Urbana, Ill.
Washington, D. C.	Apr. 9, '03	Philander Betts	H. C. Eddy, 806 Westory Building, Washington, D. C.

Total, 25

Sections and Branches—Directory.

BRANCHES	Organization authorized by Board of Directors	Chairman	Secretary
Arkansas, Univ. of....	Mar. 25, '04	C. R. Rhodes	F. S. White, 523 North Willow St., Fayetteville, Ark.
Armour Institute......	Feb. 26, '04	Edward Sherwin	J. E. Snow, Armour Inst. Tech., Chicago, Ill.
Case School, Cleveland	Jan. 8, '09	K. E. Norton	A M. Klingman, Case School of App. Science, Cleveland, O.
Cincinnati, Univ. of...	Apr. 10, '08	C. R. Wylie	C. A. Winder, 815 2nd Nat'l Bank Bldg. Cincinnati, O.
Colorado, Univ. of.....	Dec. 16, '04	H. H. Watters	L. D. Jones, Univ. of Colorado, Boulder, Colo.
Iowa State College....	Apr. 15, '03	Frank K. Shuff	M. W. Pullen, Iowa State College, Ames, Ia.
Kansas State Agr. Col..	Jan. 10, '08	W. L. Enfield	W. C. Lane, Kan. State Agr. Col., Manhattan, Kan
Kansas, Univ. of......	Mar. 18, '08	Ray Jones	E. J. Thiele, 1042 Tennessee Street, Lawrence, Kan.
Lehigh University.....	Oct. 15, '02	W.W. Broadbend	Howard M. Fry, Lehigh University, Bethlehem, Pa.
Lewis Institute........	Nov. 8, '07	R. M. Walker	P. B. Woodworth, Lewis Institute, Chicago, Ill.
Maine, Univ. of.......	Dec. 26, '06		Gustav Wittig, Univ. of Maine, Orono, Me.
Michigan Univ. of....	Mar. 25, '04	H. F. Baxter	P. R. Moffett, 1335 So. State St., Ann Arbor, Mich.
Missouri, Univ. of.....	Jan. 10, '03	H. B. Shaw	H. D. Carpenter, Univ. of Missouri, Columbia, Mo.
Montana Agr. Col.....	May 21, '07	C. S. Kennedy	J. A. Thaler, Montana Agr. Col., Bozeman, Mont.
Nebraska, Univ. of....	Apr. 10, '08	Geo. H. Morse	L. B. Hurts, Lincoln Tel. Co., Lincoln, Neb.
New Hampshire Col...	Feb. 19, '09	A. M. Buck	E. R. Fellows
Ohio State Univ......	Dec. 20, '02	F. W. Funk	F. C. Caldwell, Ohio State Univ., Columbus O.
Oregon State Agr. Col..	Mar. 24, '08	S. H. Graf	C. Christiansen State Agricultural College, Corvallis, Ore.
Penn. State College....	Dec. 20, '02	E. A. Wilcox	H. S Amer, Penn. State College, Pa.
Purdue Univ..........	Jan. 26, '03	J. W. Esterline	H. T. Plumb, Purdue Univ., Lafayette, Ind.
Stanford Univ........	Dec. 13, '07	C. L. Bradley	C. P. Taylor, Stanford Univ., California.
Syracuse Univ........	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse Univ., Syracuse, N. Y.
Texas, Univ. of.......	Feb. 14, '08	A. C. Scott	B. E. Kenyon, Univ. of Texas, Austin, Tex.
Wash. State Col. of...	Dec. 13, '07	H. V. Carpenter	M. K. Akers, State Col. of Wash., Pullman, Wash.
Washington Univ.....	Feb. 26, '04	C. M. Duncan	H. F. Thomson, 5011 Washington Ave., St. Louis, Mo.
Worcester Poly. Inst..	Mar. 25, '04	Ray H. Taber	Albert A. Nims, Worcester Poly. Inst., Worcester, Mass.

Total, 26.



The American Institute of Electrical Engineers
congratulates Charles L. Buckingham one of its
thirty living charter members on the occasion of the
Twenty-fifth Anniversary of its Organization
and presents this
Certificate of Charter Membership

in recognition of the foresight and enterprise which led to the foundation of our National Society on April Fifteenth Eighteen Hundred and Eighty-four, to "Promote the Arts and Sciences connected with the production and utilization of Electricity."

By Order of the Board

Ralph W. Pope
Secretary.

Louis A. Ferguson
President.

Certificate of Charter Membership presented to Charles L. Buckingham, Esq
Mr. Buckingham was born at Berlin Heights, Ohio, October 14, 1852.
He died at New York, May 31, 1909.

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE A. WARDLAW, Editor

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Vol. XXVIII **August, 1909** No. 8

The Twenty-sixth Annual Convention

The twenty-sixth annual convention of the American Institute of Electrical Engineers was called to order at 10 a.m. Monday, June 28 by President Ferguson in the banquet hall of the Hotel Frontenac, Thousand Islands, N. Y. The attendance at the opening session was unusually large, many members and guests having arrived on the previous two days. The registration for the entire convention reached a total of 286. The weather conditions were perfect, and the time allotted for the technical sessions, as well as for recreation was so apportioned that all events passed off in the most satisfactory manner. The convention program was carried out, as follows:

MONDAY, JUNE 28.

MORNING SESSION—10 A.M.

1. President's Address.

In his address to the convention on "The Centralization of Power Supply" President Louis A. Ferguson discussed the economies and continuity of service resulting from the centralizing of small plants in large generating stations.

After the conclusion of the presidential address Mr. Lewis B. Stillwell, the president-elect, was escorted to the platform and formally introduced to the convention by President Ferguson. Mr. Stillwell referred to the progressive management of the Institute in the past, and the great opportunity now offered for the engineer, not only to make himself useful in the advancement of the public welfare, but also to become a more important factor in the administration of affairs.

2. *The Convection of Heat from Small Copper Wires*, by A. E. KENNELLY, C. A. WRIGHT AND J. S. VAN BYLEVELT.
3. *Alternator for* 100,000 *Cycles*, by E. F. W. ALEXANDERSON.
4. *Method of Testing Transformer Core Losses Giving Sine-wave Results on Commercial Circuits*, by L. W. CHUBB.
5. *Testing of Transformer Steel*, by M. G. LLOYD AND J. V. S. FISHER.

AFTERNOON SESSION—2 P.M.

6. *A Sketch of the Theory of the Adjustable Speed, Single-Phase, Shunt, Induction Motor*, by F. CREEDY.
7. *Repulsion Motor with Variable-Speed, Shunt Characteristics*, by E. F. W. ALEXANDERSON.
8. *The Heating of Induction Motors*, by A. MILLER GRAY.
9. *Reduction in Capacity of Polyphase Motors Due to Unbalancing in Voltage*, by S. B. CHARTERS, JR., AND W. A. HILLEBRAND.

10. *The Current Locus of the Single-Phase Induction Motor*, by A. S. LANGSDORF.

11. *Multispeed Induction Motors*, by H. G. REIST AND H. MAXWELL.

RECEPTION

The reception Monday evening was a delightful affair, the receiving line including President and Mrs. Louis A. Ferguson, Vice-President and Mrs. James G. White, Vice-President Calvert Townley and his mother, Mrs. C. C. Townley, President-elect and Mrs. Lewis B. Stillwell, and Chairman Charles W. Stone of the convention committee. The reception was followed by dancing, music being furnished by the hotel orchestra, consisting of five stringed instruments.

TUESDAY, JUNE 29.

A regular meeting of the Board of Directors was held at 9.30 a.m. on Tuesday, June 29. The directors present were Messrs. Louis A. Ferguson, J. G. White, Calvert Townley, Paul Spencer, Paul M. Lincoln, W. G. Carlton, Morgan Brooks, Chas. W. Stone, Ralph W. Pope, D. B. Rushmore, and P. H. Thomas. At this meeting 169 Associates were elected, 13 Associates transferred to the grade of Member, and 38 students enrolled. [The list of Associates elected and transferred will be found elsewhere in Section I of this PROCEEDINGS.]

MORNING SESSION—10 A.M.

12. *Output and Regulation in Long-Distance Lines*, by P. H. THOMAS.

13. *Calculation of the High-Tension Line*, by P. H. THOMAS.

14. *Even Harmonics in Alternating-Current Circuits*, by J. B. TAYLOR.

15. *The Resistance and Reactance of Armored Cables*, by J. B. WHITEHEAD.

16. *Losses, Induced Volts and Amperes in Armor and Lead Cover of Cables*, by H. W. FISHER.

During the Tuesday morning session the women started at 10 o'clock on a steamboat trip of 2½ hours' duration among the islands of the St. Lawrence River, returning after rounding Heart Island opposite Alexandria Bay.

After the adjournment of the Tuesday morning session a qualifying round for the handicap golf tournament was played. A women's putting contest also took place at 5 p.m.

EVENING SESSION—8 P.M.

17. *Corona Phenomena in Air and Oil and their Relation to Transformer Design*, by W. S. MOODY AND G. FACCIOLI.

18. *Surges on Cable Systems with Aluminum Cell Protection*, by E. E. F. CREIGHTON AND S. D. SPRONG.

19. *Split-Pole Converters and Storage-Battery Regulation*, by J. L. WOODBRIDGE.

In the evening a bridge-whist tournament was played by a suitable number of the women, the prize winners being Mrs. J. M. Wakeman and Miss Alice A. Reed.

SECTIONS DINNER

The Section delegates, Branch representatives, past and present officers of the Institute, over forty in number, dined together in the evening, and, under the direction of Chairman Paul Spencer a very interesting conference was held, bearing upon the work of the local organizations. The Board of Directors and 25 Sections and Branches were represented.

WEDNESDAY, JUNE 30.

PAST-PRESIDENTS, CONFERENCE

President Ferguson and President-elect Stillwell breakfasted on Wednesday morning with Past-presidents Martin, Scott, Steinmetz, and Sprague. Nearly three hours were devoted to an informal discussion of Institute affairs.

MORNING SESSION—10 A.M.

20. *Function of Fly-wheels in Connection with Electrically Operated Rolling Mills*, by H. C. Specht.
21. *Alternating-Current Motors versus Direct-Current Motors in Steel Mills*, by K. A. Pauly. [Read by title.]
22. *Rolling Mill Motors*, by E. W. Yearsley.
23. *Electric Driven Rolling Mills*, by E. Friedlander.
24. *Power Requirements for Rolling High Carbon Steel of Small Section*, by B. Wiley.
25. *Electrical Control for Rolling-Mill Motors*, by C. T. Henderson.
26. *Automatic Motor Control*, by H. E. White.

PARALLEL SESSION—WEDNESDAY 10 A.M.

27. *Some Considerations in Designing Heavy-Capacity Fuses*, by L. W. Downes.
28. *Comparative Costs of 25-cycle and 60-cycle Alternators*, by C. J. Fechheimer.
29. *Calculation of Iron Losses in Dynamo Electric Machinery*, by I. E. Hanssen.
30. *Auxiliary Poles for Direct-Current Machines*, by J. N. Dodd.
31. *Electric Measurements on Circuits Requiring Current and Potential Transformers*, by L. T. Robinson.
32. *Electromotive Force Wave-Shape in Alternators*, by C. A. Adams.

Baseball

Following the Wednesday morning's sessions a baseball game was played between two teams selected by Captains A. A. Gray and E. A. Wagner.

The score:

Has Beens.	Never Wases.
Hall,	Sargent,
Lee,	‡Langsdorf,
Knight,	Lincoln,
Waddell,	Tillman,
Lloyd,	Norris,
Wagner,	Cole,
Schalck,	Gray,
Bauvelt,	Downes,
Koiner,	Osgood.

‡Disabled.

Score.

Never Wases—Captain Gray, 21
Has Beens—Captain Wagner, 20.

Innings, 6.

Casualties, 1, (dislocated shoulder).

No man failed to make at least one run. Greatest number of runs, Koiner, 4.

Umpire, George F. Sever.

(Signed) Ellery B. Paine,
Official Scorer.

Driving Contest

A golf "driving" contest followed the ball game, Comfort A. Adams winning first prize with a score of 28, and Charles W. Stone, second, with a score of 27.

Educational

On Wednesday evening Past-president Steinmetz was host at an informal dinner, covers being laid for 16 of the members interested in education. Dugald C. Jackson presided as chairman, the following being among those taking part in the discussion: Messrs. Brooks, Jackson, Karapetoff, Magnusson, Scott, and Steinmetz. Later in the evening nearly all the convention party embarked on the steamboat St. Lawrence for a searchlight excursion among the islands for a distance of about 25 miles. Music and light refreshments were provided by the convention committee.

Fishing Contest

One of the interesting and continuous features of the outdoor sports was the fishing contest, the entrants being J. H. Finney, C. W. Ricker, H. L. Wallau, H. W. Fisher, C. F. Scott, Andrew Pinkerton, F. H. Gale, and R. N. Davidson. The first prize for the largest fish was awarded to J. H. Finney for a 6½ lb. pickerel; the second prize for the largest catch to F. H. Gale for four pickerel weighing 11¾ lbs.

THURSDAY, JULY 1.

MORNING SESSION—10 A.M.

33. *The Modern Telephone Cable,* by F. B. JEWETT. [Read by title.]

34. *The Training of Non-Technical Men,* by C. R. DOOLEY.

35. *The Value of the Classics in Engineering Education,* by C. P. STEINMETZ.

36. *Pole-Face Losses,* by C. A. ADAMS, A. C. LANIER, C. C. POPE, AND C. O. SCHOOLEY.

PRESENTATION OF PAST-PRESIDENT'S BADGE

At the close of the last session of the convention on Thursday morning, Mr. D. B. Rushmore, in behalf of a number of the directors, presented a past-president's badge to President Ferguson. In response President Ferguson made a brief address, thanking the donors for their courtesy, and adding that his term of office of president of the Institute had brought him the happiest and most profitable year of his life.

GOLF FINALS

The final round in the golf tournament was played Thursday afternoon between the survivors, L. A. Ferguson scratch, and A. I. Totten with an allowance of 12, who won the round by a single stroke.

THE PRIZE WINNERS

Bridge-whist. Mrs. J. M. Wakeman 1. Gold mounted pin. Miss Alice A. Reed 2. Gold bar-pins.

Golf putting match. Mrs. L. A. Ferguson 1. Silver card case. Miss Alice A. Reed 2. Gold belt buckle. Mrs. F. E. Donohoe 3. Topaz hat pin. Tied for third and played off with Mrs. W. I. Slichter and Mrs. H. G. Reist. Each of the contestants in this match also received a silver card case pencil.

Golf driving. Comfort A. Adams 1. Silver cigarette box. Charles W. Stone 2. Silver match box.

Fishing. John H. Finney 1. Silver flask. Frank H. Gate 2. Pair briar pipes.

Handicap Golf. A. I. Totten, winner, large decanter. L. A. Ferguson, runner up, small decanter. Francis E. Donohoe, best gross score, mahogany humidor. Frank P. Cox, best net score, silver safety razor set.

Local Sections Conference

At the dinner of the Section delegates, Branch representatives, directors and past presidents of the Institute at Hotel Frontenac June 29, Chairman Paul Spencer in opening the conference stated that its main object was to ascertain the views and practice of the different sections, and called upon J. B. Whitehead of Baltimore, who spoke of the educational influence of the meetings. The work of a section depended largely on the chairman and secretary. There must be an incentive in order to have good meetings. They had undertaken the plan of having each member of the executive committee in turn guarantee a speaker for each meeting.

Dugald C. Jackson of Boston stated that their meetings lacked spontaneity. They had arranged for a committee on discussion in order to attain better results. There were too many meetings which detracted from attendance.

Charles Abbott of Chicago spoke of their experience in joint meetings. The Western Society of Engineers covered all branches of engineering and had an electrical section. An arrangement had been put into practice by which alternating joint meetings were held under the chairmanship of the local officer of the Institute and the Western Society in turn. The average attendance at these meetings had been about 200. He thought more of the section papers should be printed, and larger appropriations made.

President Ferguson was of the opinion that the whole question was up to the sections locally, and they should not depend too much upon visiting speakers. Creditable papers should be published and the work of the sections should be encouraged. He believed there had been considerable improvement, but little advancement could be made in one year.

C. Wellington Koiner of Los Angeles stated that when their section was organized about a year ago there were 38 members, and the number had been brought up to 125. All their papers were of local origin, and so much interest had been shown that it was difficult to close a meeting at a reasonably early hour. They had a good working secretary and a large attendance in proportion to the membership. They had found there were many electrical engineers who were not members, and they were gradually bringing them in. They made a practice of arranging for meetings a month or two in advance. The Pacific Coast wanted recognition, and would be glad to have the Annual Convention of 1910 held in Los Angeles, although the exact location was not insisted upon.

Carl E. Magnusson of Seattle said that some of their original papers had been printed. They would like to have prominent engineers appear at their meetings whenever possible. Consulting engineers frequently visited in their vicinity and he hoped some of them would so apportion their time as to meet with them and speak at their meetings. They had but five local members and about 100 Members and Associates. They were well satisfied with their treatment.

E. P. Peck of Atlanta reported that there were no local members in that Section. More money was required for their work, and a feeling existed that the Institute was rather a New York than a national body.

M. O. Troy of Schenectady said he had no criticisms to make. The local members at Schenectady had made the Section self-sustaining, and a bank balance had been brought forward sufficient to carry on the work another year. They had popular talks on engineering subjects, frequently illustrated with lantern slides, also lectures, and during each season two smokers for the purpose of promoting acquaintanceship and sociability. A question and answer department had also been organized which was found useful to the younger members. It had been found by experience that weekly meetings were too frequent, and next season but two meetings would be held each month.

D. B. Rushmore spoke in favor of development of the local membership feature of the Sections, and also the necessity of technical divisions. Societies had been formed of electrochemists, illuminating engineers, wireless operators and possibly others because the Institute as organized had not been able to specialize on these subjects. The American Society of Mechanical engineers had started a Gas Power Section. We had endeavored to meet similar conditions by the appointment of High-Tension, Industrial Power and Railway committees. There should exist many times the present number of sections. Our work should be extended and there is no doubt in the vicinity of all Sections a number of men who can be brought in as local members. In addition to this extension of work, a lecture bureau should be organized with a collection of lantern slides, and arrangements made for getting speakers.

C. P. Steinmetz outlined a plan for the organization of affiliated societies which should be independently governed, representing various branches of electrical engineering, each having its own series of printed transactions, which, however, would be available to members of the Institute under certain conditions which would not be so expensive as the present cost of membership in the various existing societies.

After a session of about three hours the conference adjourned. The following officers and delegates attended the Section Conference:

Past-Presidents:

- C. P. Steinmetz,
- T. C. Martin.
- Frank J. Sprague.
- Charles F. Scott.

Officers of the Institute:

- Louis A. Ferguson.
- Paul M. Lincoln.
- David B. Rushmore.
- Percy H. Thomas.
- J. G. White.
- Calvert Townley.
- Morgan Brooks.
- W. G. Carlton.
- Ralph W. Pope.

Section Delegates:

Atlanta—E. P. Peck.
Baltimore—J. B. Whitehead.
Boston—D. C. Jackson.
Chicago—W. L. Abbott.
Cleveland—C. W. Ricker.
Cleveland—H. L. Wallau.
Fort Wayne—E. A. Wagner.
Ithaca—Frederick Bedell.
Ithaca—E. L. Nichols.
Los Angeles—C. W. Koiner.
Madison—M. C. Beebe.
Mexico—Wm. B. Hale.
Philadelphia—Paul Spencer.
Pittsburgh—Henry W. Fisher.
Pittsburgh—W. Edgar Reed.
Portland, Oregon—L. B. Cramer.
Pittsfield—W. A. Hall.
Schenectady—M. O. Troy.
Seattle—C. E. Magnusson.
St. Louis—A. S. Langsdorf.
Toledo—C. E. Robertson.
Urbana—Ellery B. Paine.
Washington—M. G. Lloyd.
Toronto—T. R. Rosebrugh.

Branch Representatives:

University of Texas—B. E. Kenyon
Worcester Poly.Inst.—Ray H. Taber
Lewis Institute—Prof. Woodworth.

Invited Members:

- Lewis B. Stillwell, President Elect.
- F. L. Hutchinson, Assistant Secretary
- A. A. Gray, Managing Editor, *Electrical Review and Western Electrician*.

Minutes of June Meeting of the Institute

As noted in the story of the twenty-sixth annual convention, the two-hundred and thirty-seventh regular meeting of the Institute was held at Frontenac, N. Y., on Tuesday June 29, 1909. The following Associates were elected:

ADAMS, LEE FRANCIS, Instructor in Electrical Engineering, Pennsylvania State College; res., 103 Allen St., State College, Pa.

ADAMS, RALPH FRANKLIN LOWELL, Assistant Engineer, General Electric Co., West Lynn; res., 871 E. Fourth St., So. Boston, Mass.

ANTHONY, CHARLES C., Manager, Palo Alto Electrical Works; res., 235 University Ave., Palo Alto, Cal.

ARAKAWA, BUNROKU, Assistant Professor in Electrical Engineering, The Tokyo Imperial University, Tokyo, Japan.

BALLING, GEORGE ADAM, Elec. Dept., Sanitary District of Chicago; res., 6135 Calumet Ave., Chicago, Ill.

BAMMES, PAUL T., Chief Electrician, Boston Consolidated Mining Co., Garfield, Utah.

BARNS, BIRD LEE, Steam & Electrical Dept., Allis-Chalmers Co., Milwaukee, Wis.

BARTON, ROBERT CLYDE, Engineer, Isthmian Canal Commission, Empire, Canal Zone.

BEETEM, FRANK GARDNER, Assistant Engineer, Construction Department, The Electric Storage Battery Co., Philadelphia, Pa.

BENNETT, JAMES, Chief Electrical Inspector, The Canadian Fire Underwriters' Ass'n., 524 Coristine Bldg., Montreal, Canada.

BENTZ, HENRY CHRISTIAN, Sales Manager, Western Electric Co., Minneapolis, Minn.

BLATHY, OTTO TITUS, Consulting Engineer, Ganz Electric Co., Ltd., 11 Retekutca, Budapest, Hungary.

BOETTNER, JOHN, JR., Central Station Engineer, Isthmian Canal Commission, Empire, Canal Zone.

Boring, George Albert, Commercial Engineer, General Electric Co.; res., 717 Marion Street, Seattle, Wash.

Bott, Thomas Wilson, Chief Electrician, Old Dominion Copper Mining & Smelting Co., Globe, Arizona.

Breese, Robert Hume, Electrical Inspector, The Southeastern Underwriters' Association, Atlanta, Ga.

Buchanan, Myron Webster, Bureau of Construction and Repair, United States Navy Dept., Washington, D. C.

Bunnell, Charles Montrose, Special Representative, Lamp Sales Dept., General Electric Co., Harrison; res., Newark, N. J.

Callahan, Edward F., Tester, General Electric Co.; res., 104 Jay St., Schenectady, N. Y.

Carleton, Robert Arthur, Electrical Engineer, Newton & Watertown Gas Lt. Co., Newton; res., 13 Hobart St., Brighton, Mass.

Chandler, Charles De Forest, Captain, Signal Corps, United States Army, Washington D. C.

Chaphe, James Lawrence, Electrical Engineer, Cazenovia Electric Co., Cazenovia, N. Y.

Chubb, Lewis Warrington, Research Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 410 Todd St., Wilkinsburg, Pa.

Clark, Harold Hayward, Electrical Engineer, United States Geological Survey, 40th & Butler Sts., Pittsburg, Pa.

Clarke, Robert B., Electrical Assistant, Smith, Kerry & Chace; res., 313 Spadina Ave., Toronto, Ont.

Combs, Albert Franklyn, Chief Electrician, Home Telephone Co.; res., 543 N. Union St., Portland, Ore.

Cook, Charles Stetson, Manager Railway & Lighting Dept., Westinghouse Elec. & Mfg. Co.; res., 335 S. Fairmont St., Pittsburg, Pa.

Coriell, Louis Duncan, Commonwealth Bank Building; res., 1908 Linden Ave., Baltimore, Maryland.

Crowley, Valentine Janus, Operator, Oro Water, Light & Power Co., Oroville; res., Cherokee, Cal.

Crowley, Wayland Ayer, Foreman, Electrical Dept., The Philadelphia Electric Co., Philadelphia; res., 414 Colwyn Ave., Colwyn, Pa.

Cryder, Ross Warner, Erection and Operating Engineer, Guanica Centrale Co., Ensenada, Porto Rico.

Darrah, William Austin, 1164 44th St., Brooklyn, N. Y.

Davies, Charles Edward, Chief Operator & Electrician, The Great Northwestern Telegraph Co., Ottawa, Ont.

Davis, William Ralph, Patent Lawyer and Solicitor, 220 Broadway, New York City; res., Westfield, N. J.

De France, Mac Errett, Chief Engineer, Mobile Light & Railway Co., Mobile, Alabama.

Doud, Willard, Shops Engineer, C. B. & Q. R.R. Co., Room 60, 209 Adams Street, Chicago, Ill.

Doying, William Albert Edward, Inspecting Engineer, The Isthmian Canal Commission; res., 1627 Lamont St., Washington, D. C.

Drennen, Charles Eugene, Electrical Engineer, The Hendrie & Bolthoff Mfg. & Supply Co., Denver, Colo.

Drury, Guy Lyndon, Car Shed Superintendent, North Eastern Ry. of England, Walker Gate, Newcastle-on-Tyne, England.

Dunham, Harry E., Associate Editor, The Telegraph Age, New York City; res., 18 St. James Place, Brooklyn, N. Y.

Dunn, Douglas Penyer, Substation Operator, British Columbia Electric Railway Co.; res., 1178 Pender St., Vancouver, B. C.

Dwyer, Roy Clark, Apprentice, Westinghouse Electric & Mfg. Co., Pittsburg; res., 512 Kelly Street, Wilkinsburg, Pa.

Edgerton, Arthur Duncan, Chief Operator, The Philadelphia Rapid Transit Co., Philadelphia; res., 123 East Chelten Ave., Germantown, Pa.

Edwards, Evan James, Assistant in Electrical Engineering, Mass. Inst. of Technology, Boston; res., 23 Alaska St., Roxbury, Mass.

EHRENBORG, GOSTAF BRAMWELL, Partner, The Magnet Electrical Co., 209–210 Boston Blk., Seattle, Wash.

ELBEL, ADOLPH CHRISTIAN, Electrician, Electrical Department, City of Chicago; res., 269 Park Ave., Chicago, Ill.

ENDERWIES, GROVER TILDEN, Wireman and Repairman, Mexican Light & Power Co., Necaxa, Puebla, Mexico.

EVANS, LOUIS MILTON, Electrical Assistant, Signal Corps, United States Army, 408 No. Alfred St., Alexandria, Va.

FARR, RILEY WILLIAM, JR., Electric Meter Foreman, Peekskill Ltg. & Ry. Co., Peekskill; res., 35 State St., Ossining, N. Y.

FILER, CHARLES FREDERICK, Electrical Engineer, Robinson Electrical Contracting Company, Miami, Florida.

FINELY, WILHELM CHARLES JOHN, Superintendent Sacramento Power Division, Pacific Gas & Elec. Co., Sacramento, Cal.

FISHER, HARRY ALBERT, Foreman, W. A. Jackson Co., 130 W. Van Buren St.; res., 291 Flournoy St., Chicago, Ill.

FORGEE, FREDERICK ANGUS, Consulting Engineer, 5 Beekman Street, New York City.

FOX, JAMES J., Tester in Meter Dept., Public Service Corporation; res., 73 South 7th Street, Newark, N. J.

FREEMAN, ERNEST HARRISON, Professor of Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

FRITCH, LOUIS CHARLTON, Consulting Engineer, Illinois Central Railroad, 1 Park Row, Chicago, Ill.

GLASS, WILLIAM MINOR, Chief Engineer, Municipal Electric Light Plant; res., 436 So. Hudson Ave., Pasadena, Cal.

GREEN, FRANK CRAUCH, Transformer Engineering Dept., General Electric Co., Pittsfield, Mass.

GRIDLEY, SIDNEY DIAS, Student, Cornell University; res., 105 De Witt Place, Ithaca, N. Y.

GUERRA, ABRAHAM, Electrical Engineer Apprentice, The Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

HALLADAY, OLANDO WILBERT, The Newton & Watertown Gas Lt. Co., Newton; res., 41 Fayette St., Watertown, Mass.

HALLIGAN, HOWARD ANSEL, Vice President, Western Electric Co., 463 West St., New York City.

HARDING, WILLIAM ROLANDE, Asst. Engineer to Engineer-in-Chief, The National Telephone Co., Ltd., London, E. C., Eng.

HAROLD, WILLIAM HENRY, Manager, Clay Center Light & Power Company, Clay Center, Kansas.

HARVEY, ALBERT LEE, Foreman, Union Electric Co.; res., 1026 G. Street, Lincoln, Nebraska.

HENDERSON, SAMUEL ERNEST MCMILLAN, Electrical Engineer, General Electric Co.; res., 42 Robinson St., Schenectady, N. Y.

HERDLING, ARTHUR CLARENCE MORRIS, Equipment Man, The American Tel. & Tel. Co., New York City; res., 19 Lincoln Ave., Rutherford, N. J.

HERMANN, HENRY, Assistant Engineer, Dept. of Public Works, Chicago, Bureau of Engineering, Subway Division, Chicago, Ill.

HERSHEY, FRANK, Testing Department, General Electric Co.; res., 773 State St., Schenectady, N. Y.

HESS, STANLEY H., Telephone Engineer, The Pacific Tel. & Tel. Co., 14 New Montgomery St., San Francisco, Cal.

HICKOX, NORMAN BROADWELL, Rome Railway and Light Co., Rome, Georgia.

HIMMELSBACH, JOHN WENTZEL, Electrical Engineer, Pittsfield, Massachusetts.

HOHN, EMIL, Inspector of Building Construction, Tenement House Dept., New York City; res., 22 St. John's Place, Brooklyn, N. Y.

HOLLINGER, HARRY, Electrical Department, Pennsylvania Railroad; res., 1513 9th St., Altoona, Pa.

HORNE, HERBERT WARREN, Asst. Station Electrician, The Lowell Electric Light Corporation, Lowell, Mass.

Hovey, Shirley S., Student, State University of Iowa; res., 129 N. Capitol St., Iowa City, Iowa.

Howe, Paul James, Plant Department, American Telephone & Telegraph Co., 22 Thames Street, New York, N. Y.

Hubbard, John Fanning, Ontario Power Co., Niagara Falls, N. Y.

Hull, Arthur Harvey, Electrical Engineer, Smith, Kerry & Chace; res., 140 D'arcy Street, Toronto, Ont.

Jacobs, Harry Monroe, Cost Estimator, General Electric Co.; res., 827 Lincoln Ave., Schenectady, N. Y.

Jenks, Harrie Lee, 457 58th Street, Brooklyn, N. Y.

Jessup, Albert H., Floor Operator, Stanislaus Electric Power Co., Vallecita, Cal.

Kaarsberg, Lawrence C. H., Electrical Draftsman, Mare Island Navy Yard; res., Vallejo, Cal.

Kauffman, Roy, Meter Tester, Seattle-Tacoma Power Co.; res., 102 Valley Street, Seattle, Wash.

Keller, William Henry, Consulting Engineer, 907 Kanawha Street, Charleston, West Virginia.

Kelly, Daniel Joseph, Chief Electrician, Detroit Copper Mining Co., Morenci, Ariz.

Kelterborn, August G., Draughtsman, Metropolitan Street Railway Co.; res., 966 Sixth Ave., New York City.

Kibbe, Glen E., Assistant Electrical Engineer, with W. S. Barstow & Co., 419 Failing Bldg., Portland, Ore.

Kirk, T. Edgar, Construction Engineer, The Electric Storage Battery Co.; res., 3441 Smedley St., Philadelphia, Pa.

Kleine, William Oscar, Estimator & Supt. of Construction, The Devere Electric Co.; res., 2927 Euclid Ave., Cincinnati, Ohio.

Kurtichanof, Leonard, Assistant Chief Electrician, Seattle Electric Co., Seattle, Washington.

Lacke, William Albert, Draughtsman, Indiana Steel Co., Gary, Indiana, res., 9614 Avenue L, Chicago, Ill.

Lawrence, Howard F., Assistant Switchboard Operator, N. Y. Edison Co., Waterside Station; res., 217 West 110th St., New York City.

Lee, Ernest Eugene, Assistant Engineer, The Isthmian Canal Commission, Culebra, Canal Zone, Panama.

Levings, Sherburne Davis, Assistant Engineer, McMeen & Miller, 1454 Monadnock Block, Chicago, Ill.

Lincoln, Henry Lewis, Tester, General Electric Co.; res., 33 Front Street, Schenectady, N. Y.

Logan, Clyde Campbell, Head of Order Dept., Western Electric Co., Chicago; res., 443 Marengo St., Forest Park, Ill.

Loughridge, Matthew Harkness, Draftsman, Signal Dept., N. Y. C. & H. R. R.R.; res., 341 West 34th St., New York City.

Lovell, William Wayne, Salesman, Canadian Westinghouse Co., Ltd., 1207 Traders Bank Bldg., Toronto, Canada.

Lozier, Isaac Newman, Superintendent, The Electric Light & Water Co., Sandersville, Ga.

Mac Williams, James Fred, Electrical Engineer, The Lehigh Coal & Navigation Co., Lansford, Pa.

Marsh, Leon John, Testing Department, General Electric Co., Lynn; res., 35 Day Street, W. Somerville, Mass.

Marshall, John Carter, Superintendent of Construction, Laredo Electric & Railway Co., Laredo, Texas.

Martin, George Rowland, Inspector, The Boston & Northern Street Railway Co.; 31 Cumberland St., Boston, Mass.

Masterson, Wilmer Dallam, City Superintendent of Electricity; res., 1723 31st St., Galveston, Texas.

Matthews, Claude Levering, Partner, W. N. Matthews & Brother; res., 219 N. 2nd St,. St. Louis, Mo.

McCosker, Charles S., City Electrician; res., 264 St. Francis St., Mobile, Ala.

McKennon, Basil Clement, Superintendent Meter Dept., Shreveport Gas, Electric Light & Power Co., Shreveport, La.

McNiece, Irwin, Local Manager, The Beaver River Power Co., Milford, Utah.

McSoley, Frank Bartlett, Service Dept., Narragansett Electric Ltg. Co.; 585 Cranston St., Providence, R. I.

Merriell, Frank Cooper, Student, Colorado College; res., 722 North Weber St., Colorado Springs, Colo.

Merrill, Frank Winthrop, Electrical Engineer, Roth Bros. & Co.; res., 1024 N. Kedzie Ave., Chicago, Ill.

Millener, Frederick Hoyer, Experimental Electrician, The Union Pacific Railroad Co., Omaha, Neb.

Miller, Lorimer, Douglass, Electrical Engineer, Engineer, Department at Large, U. S. Army, 1015 Barristers Hall, Boston, Mass.

Moore, Fort H., Chief Electrical Inspector, Indianapolis Fire Inspection Bureau, 1003 Lemcke Bldg., Indianapolis, Ind.

Morrison, John William, Jr., Engineer, Rochester Telephone Co.; res., 59 Stone St., Rochester, N. Y.

Munson, Arthur Hale, Draughtsman, Ontario Hydro-Electric Power Commission; res., 89 Wood Street, Toronto, Ont.

Nelson, Fred C., Secretary, Northern Heating and Electric Co.; res., 835 Laurel Ave., St. Paul, Minnesota.

Nourse, Walter Edwin, Sub-Foreman of Installation Dept., The Edison Electric Ill. Co. of Boston, So. Framingham, Mass.

Orcutt, Daniel Paul, Assistant Engineer, Storage Battery Dept., Westinghouse Machine Co., East Pittsburg, Pa.

Ostermann, Rudolf Maximilian, Electrical Engineer, Sussdorff, Zaldo & Co.; res., 80 Cuba Street, Havana, Cuba.

O'Tyson, Claudius Eugene, Night System Operator, Seattle Electric Co.; res., 3013 45th Ave., S. W., Seattle, Wash.

Owen, Alden Bradford, Electrical Engineer, Ridgway Dynamo & Engine Co., Ridgway, Pa.

Palmer, Granville Ernst, Electrical Engineer, Pettengill-Andrews Co., Boston; res., 21 Lebanon St., Winchester, Mass.

Parker, Thomas Harry, Electrical Engineer, United Railroads of San Francisco; res., 318 Jules Avenue, San Francisco, Cal.

Peavey, James Edward, Superintendent of Exchange and Equipment, The Cincinnati & Suburban Bell Tel. Co., Cincinnati, Ohio.

Peeling, Charles U., Student, Queens University, Kingston, Ontario.

Pettis, Charles Roberts, 1st Lieutenant, Corps of Engineers, United States Army, Vancouver Barracks, Wash.

Phelan, Paul Louis, Manager, Machinery Department, Geo. W. Lane & Co., 93 Front St., New York City.

Phillips, David J., Superintendent of Electrical Dept., Board of Education; res., 194 Lawnsdale St., Portland, Ore.

Poole, John Hudson, Superintendent of State, War & Navy Dept., Bldgs., Room 150, War Dept., Washington, D. C.

Pragst, Ernest, William, Test Man, General Electric Co.; res., 618 Chapel St., Schenectady, N. Y.

Preston, James Chandler, Chief Load Dispatcher, New York, New Haven & Hartford R.R. Co., Cos Cob, Conn.

Rankin, Charles Oliver, Entiat, Wash.

Rao, Mysore Giriappa, Gopalkrishna Electrical Engineer, 317 Setha Vilasa Agrahar, Mysore, South India.

Rees, Anson Harvey, General Storekeeper, The Ventura County Power Co., Oxnard, Cal.

Reynolds, Charles William, Division Supt. of Plant, The Pacific Tel. & Tel. Co.; res., 171 King St., Portland, Ore.

Rockwood, John Alvah, Asst. to Supt. of Construction, W. S. Barstow & Co., 419 Failing Bldg., Portland, Ore.

ROGERS, HERBERT THOMAS, Student, Stanford University; res., 381 E. San Salvador Street, San Jose, Cal.

ROGERS, JOHN BERNARD, Electrical Engineer, The La Crosse Water Power Co., Hatfield, Wis.

ROTH, CHARLES, Electrical and Mechanical Engineer, Liquid Carbonic Co., Wells & Michigan Streets, Chicago, Ill.

RYAN, RICHARD R., Assistant Engineer, with Gardner S. Williams, 230 N. 3d St., Phoenix, Arizona.

SANFORD, ARTHUR LEVERETT, Draftsman, B. F. Sturtevant Co., 329 West Third St., Cincinnati, Ohio.

SCHWENDENER, HARRY GARFIELD, Chief Engineer, Toasted Corn Flake Co., Battle Creek, Michigan.

SCOTT, FRED WILKIE, Transmission Engineer, Hydro-Electric Power Commission of Ontario; res., 6 Grange Ave., Toronto, Ont.

SECREST, CHARLES MAHLON, Student, State University of Iowa; res., 609 Summit St., Iowa City, Iowa.

SEWELL, HENRY ROLLO, Assistant Engineer, The Brush Electric Light & Power Co., Galveston, Texas.

SHEARER, DAVID ROBERT, Electrician and Draftsman, Braid Electric Co., Nashville, Tennessee.

SHEPARD, WILLIAM MARTIN, Supply Salesman, General Electric Co., San Francisco, Cal.

SIMMONS, EUGENE, City Electrician and Superintendent, Marshall, Minn.

SOARES, JOHN STANISLAUS, Chief Electrician, Yuba Construction Co., Marysville, Cal.

SPROAT, DORR W., Chief Electrician, Dwight Mfg. Co.; res., 10 Myrtle St., Chicopee, Mass.

STEELE, WILLARD ROY, Assistant in Research Laboratory, General Electric Co.; res., 36 Euclid Ave., Schenectady N. Y.

STEVENS, WILLIAM HARRY, Inspector of 3rd Rail and Track Bonding, N. Y. C. & H. R. R.R.; res., 381 East 157th St., New York City.

THEIS, ADOLPH J., Assistant Electrical Engineer, San Francisco Gas & Electric Co.. San Francisco, Cal.

THOMAS, HENRY, Erecting Engineer, Electrical Dept., Allis-Chalmers Co., 71 Broadway, New York City.

UNGER, MAGNUS, Electrical Engineer, General Electric Co.; res., White Terrace, Pittsfield, Mass.

WALLIS, ROLLAND SCHANEL, Student, Iowa State College; res., 617 State St., Ames, Iowa.

WARREN, ALBA HOUGHTON, Manager, Pensacola Electric Co., Pensacola, Florida.

WEBB, RICHARD LOANE, Commercial Engineer, Viele, Blackwell & Buck, 49 Wall Street, New York City.

WELCH, LEO THOMAS, Chief Engineer, Welch Brothers & Co., res., 58 Columbia St., Albany, N. Y.

WESSEL, JOHN FREDERICK, Electrical Engineer, Lynchburg Traction & Light Co., Lynchburg, Va.

WILKINS, FREDERICK HAYES, Manager, Western Electric Co., 463 West St., New York City.

WILLIS, RALPH S., Chief Engineer, New Castle Power House, The Mohoning & Shenango Ry. & Lt. Co., Youngstown, Ohio.

WILSON, JOHN HAROLD, Superintendent of Power, Berlin Mills Co., Berlin, N. H.

WOLFF, ANDREW J., Salesman, Portland Iron Works, Portland, Ore.

WOODVILLE, ARTHUR WELLESLEY, Salesman, The Westinghouse Electric & Mfg. Co., Central Bldg., Seattle, Wash.

WORTH, BARZILLAI GARDNER, JR., Electrical Engineer, with Walter Kidde, 140 Cedar St., New York City.

ZOGBAUM, FERDINAND, Student, Columbia University; res., 125 W. 87th St., New York City.

Total, 169.

The following Associates were transferred to the grade of Member:

WILSON LEE CAMPBELL, Gen. Sup't., Automatic Electric Co., Chicago, Ill.

Herbert S. Evans, Professor of E. E., University of Colorado, Boulder, Colo.

F. A. Fish, Professor of E. E., Iowa State College, Ames, Iowa.

H. A. Holdrege, Gen. Mgr., Omaha Electric Light & Power Co., Omaha, Neb.

Thomas Duncan, E. E. and Managing Director, Duncan Electric Mfg. Co., Lafayette, Indiana.

Milan V. Ayres, E.E., Boston & Worcester Ry., South Framingham, Mass.

Rudolf Emil Hellmund, E.E., W. E. & M. Co., Pittsburgh, Pa.

Russell Stimson Feicht, E.E., W. E. & M. Co., Pittsburgh, Pa.

R. F. Schuchardt, Engineer, Commonwealth Edison Co., Chicago, Ill.

Joseph F. Merrill, Director and Professor, University of Utah, Salt Lake City, Utah.

Robert Lee Wilson, E.E., Railway Construction, W. E. & M. Co., Pittsburgh, Pa.

William McClellan, V.P., The Campion-McClellan Co., New York.

Willits Herbert Sawyer, Engineer Ford, Bacon & Davis, New York City.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting.

Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before September 1, 1909.

8748 Templin, W. W., Chicago, Ill.
8749 McCraig, S. J., Montreal, Canada.
8750 Stone, H. A., Pelham, N. Y.
8751 Wilkinson, T. W., Auburn, Nebr.
8752 Worthington, C. G., Seattle, Wash.
8753 Parrish, W. C., Laramie, Wyoming
8754 Brewer, J. I., New York City.
8755 Fetherstonhaugh, E. P., Winnipeg, Man.
8756 Cooper, R. G., Detroit, Mich.
8757 Hodgson, G. O., Schenectady, N. Y.
8758 Clark, E. L., Guilford, Conn.
8759 Denton, C. F., San Juan, P. R.
8760 Schwerin, B. G., Philadelphia, Pa.
8761 Cochran, A. W., Portland, Ore.
8762 Geiger, C. F., Wilmington, Del.
8763 Johnson, S. A., Asheville, N. C
8764 Mulock, R. H., Peterboro, Ont.
8765 Mumma, F. T., Oakland, Cal.
8766 Godfrey, J. W., Yonkers, N. Y.
8767 Halliday, C., Fon du Lac, Minn.
8768 Schlingman, P. H., St. Louis, Mo.
8769 Chappell, W. C., Vancouver, B. C.
8770 Faucett, F. F., Gardiner, Mont.
8771 Hoppin, G. H., Spokane, Wash.
8772 Fenno, G. H., New York City.
8773 Hoke, C. C., Maupin, Mex.
8774 Sylwan, E., Skara, Sweden.
8775 Shepard, E. R., Portland, Ore.
8776 Laidlaw, H. A., Nome, Alaska.
8777 Rice, C. B., New Haven, Conn.
8778 Adams, I. B., Colgate, Cal.
8779 Alsaker, Alfred, Chicago, Ill.
8780 Armstrong, F. H., Vulcan, Mich.
8781 Dorsey, J. W., Schenectady, N. Y.
8782 Febrey, H. H., New York City.
8783 Foltz, T. F., New York City.
8784 Hoag, C. M., Independence, Cal.
8785 Kribs, G., Toronto, Ont.
8786 Pratt, C. N., Rochester, N. Y.
8787 Schafer, J. W., Havana, Cuba.
8788 van Bylevelt, J. S., The Hague, Holland.
8789 Winetraub, A. I. M., Havana, Cuba.
8790 Wuest, A. R., Frankfurt, Germany
8791 Holland, R. K., Ann Arbor, Mich.
8792 Gude, R. E., Davis, Cal.
8793 Parker, J. A., San Diego, Cal.
8794 Feigel, J. R., Boone, Iowa.
8795 Hawley, L. W., Brattleboro, Vt.
8796 Landes, R. C., New York City.
8797 Leilich, F. T., Pittsburg, Pa.
8798 Tangeman, C. L., Cincinnati, Ohio.
8799 Tucker, C. B., Marblehead, Mass.
8800 Case, S. L., Helena, Mont.
8801 Mitchell, N. J., New York City.
8802 Dalemont, J. E., Montreal, Can.
8803 Biesecker, A. S., Scranton, Pa.
8804 Heller, G. A., Pittsburg, Pa.
8805 Kilmore, J. B., Scranton, Pa.

Total, 58.

Applications for Transfer

Recommended for transfer by the Board of Examiners, June 22, 1909. Any objection to these transfers should be filed at once with the secretary.

RUDOLPH WARNER VAN NORDEN, Consulting Engineer, San Francisco, Cal.

GEORGE HARVEY JONES, Power Engineer, Commonwealth Edison Company, Chicago, Ill.

P. W. SOTHMAN, Chief Engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont.

ROBERT DALE MCCARTER, Consulting Engineer, London, England.

CHARLES D. KNIGHT, Electrical Engineer, General Electric Company, Schenectady, N. Y.

HANS CHRISTIAN SPECHT, Electrical Engineer, Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa.

DAVID FRANCIS CRAWFORD, General Superintendent, Motive Power, Penn. Lines West of Pittsburgh, Pittsburgh, Pa.

Conservation Pamphlet

Members who are interested in the conservation of natural resources may obtain from the secretary without charge, copies of the pamphlet containing the four papers read at the joint meeting of the four national engineering societies, March 24. The paper by Mr. Stillwell was printed in the May PROCEEDINGS. The contents of this pamphlet are:

Telegram from President William H. Taft.

Introductory Address, Dr. James Douglas.

The Conservation of Water, John R. Freeman, M. Am. Soc. C. E.

The Conservation of Natural Resources by Legislation, Rossiter W. Raymond, M. Am. Inst. M. E.

The Waste of Our Natural Resources by Fire, Charles Whiting Baker, M. Am. Soc. M. E.

Electricity and the Conservation of Energy, Lewis B. Stillwell, M. Am. Inst. E. E.

Sections and Branches

ATLANTA SECTION

In the absence of Chairman Collier, Mr. A. M. Schoen presided at the meeting of the Atlanta Section held on June 1, 1909. No original paper being available, Mr. Schoen led a discussion on the Institute paper by Dr. Steinmetz, on "Prime Movers." Mr. E. P. Peck was appointed official delegate of the Section to the Institute's annual convention.

BALTIMORE SECTION

The annual election of officers of the Baltimore Section was held at the meeting of June 4. The officers elected were: Chairman, Dr. J. B. Whitehead; secretary, Dr. L. M. Potts; Executive Committee, Messrs. Herbert A. Wagner, T. K. Cross, J. B. Scott, Harold Lomas, H. H. Seabrooke, R. N. Williams.

The paper of the evening was read by R. W. Wood, professor of experimental physics, John Hopkins University. It was accompanied by various experimental demonstrations of unfamiliar electric and magnetic phenomena. Dr. Whitehead presided at this meeting, and the attendance numbered 42.

CHICAGO SECTION

A joint meeting of the Chicago Section and the Electrical Section of the Western Society of Engineers was held on Friday, May 28, 1909. The meeting was addressed by members of the board of supervising engineers, who have in hand the work of rehabilitating the traction systems in Chicago. Messrs. Bion J. Arnold, George Weston, and H. B. Fleming, of this board, discussed at some length the work that is now under way. No formal papers were presented. Messrs. Budd, Junkersfeld, and others took part in the general discussion that followed. The meeting was one of the most successful of the season, and was attended by over 200 engineers and guests.

UNIVERSITY OF COLORADO BRANCH

At the meeting of the University of Colorado Branch on May 6 Mr. W. F.

Wright, engineer of the General Electric Company, gave an illustrated lecture on turbine-generator units. He considered the low-pressure turbines and spoke of some of the difficulties of constructing generators for use with turbines. There was an attendance of 40.

The election of officers of this Branch for the ensuing year was held at the meeting on May 20. Mr. E. A. Robertson of Boulder, Colo., was elected president; Mr. A. P. Sonnergren, secretary, and Mr. V. M. Beeler, treasurer.

FORT WAYNE SECTION

The Fort Wayne Section held its annual meeting on Thursday evening, June 10, 1909. It was decided to have the paper of the evening precede the executive session. The paper, which was illustrated by lantern slides, was presented by Mr. E.A. Wagner, and was entitled "Various Types of Transforming Apparatus." Mr. Wagner described early attempts in the construction of transformers, and then proceeded to the modern types, showing views of the more recent high-tension transformers. He spoke at some length upon the recent development in the production of insulators and insulation for modern high-tension systems. At the conclusion of the discussion on the paper, the executive business was taken up. The officers of last year were all re-elected. These officers are: chairman, E. A. Wagner; vice-chairman, J. J. Kline; secretary-treasurer, J. V. Hunter; executive committee, G. H. Kelsay, F. S. Hunting, T. R. Cook.

IOWA STATE COLLEGE BRANCH

A very successful meeting was held by this branch on March 17, 1909. Seventy-three members and visitors were present to hear a discussion by Professors Fish and Shane on "The Relative Merits of Alternating Current and Direct Current for Traction Work." In speaking of the field of the direct-current motor, Professor Shane stated that by increasing the voltage of the line the limit of economy for this system was greatly extended. He pointed out that 1200-volt systems were already in use and that they showed marked advantages over the 600-volt systems. Professor Fish in comparing the alternating- and direct-current systems worked out the performance curves for the motors of both systems. It was found that for the same horse power the alternating-current motor is the heavier, though for a long run it is more economical in its use of energy.

At the meeting of the Branch held on April 7, Mr. J. G. Boyd, of Chicago, was to have presented a paper on "Carbon Incandescent Lamps." Mr. Boyd could not be present, but the paper was read by Mr. M. W. Pullen. Messrs. Shane, King, Smith, Spinney and Fish participated in the discussion.

On the afternoon and evening of Wednesday, April 14, the Branch gave its first annual electrical show in the engineering hall of the college. Some of the principal features exhibited were: wet and dry processes of electric welding; operation of a central energy telephone system; wireless telegraphy; different types of incandescent lamps, and effects of various lamp shades; electric cooking: electric incubator; electrically driven sewing machine and washing machine; mercury arc lamp. A number of electric novelties afforded much pleasure and interest. Among these were a singing arc, the original sound emanating from a graphophone on the floor above, a phantom telephone, a miniature electric railway built by three of the Branch members and capable of bearing one person, swinging copper disc, and jumping rings. The show was a pronounced success.

The meeting of May 5 was devoted to reviews of three Institute papers. Mr. M. T. Humphrey reviewed the paper on "Industrial Application of the Electric Motor," by B. R. Shover. Mr. C. M. Sones reviewed the papers on "High-

Voltage Transformers and Protective and Controlling Apparatus for Outdoor Installation," by K. C. Randall, and "Condenser Type of Insulation for High-Tension Terminals," by A. B. Reynders. The papers were discussed by Messrs. Kirkpatrick, Smith, Shuff, Fish, Humphrey, Paulsen, Pullen, Shane, and Sones.

On Wednesday evening, May 12, the Branch held its semi-annual banquet in Alumni Hall. Professor Spinney acted as toastmaster. The program was as follows: "D. S. of E. E.", H. W. Wagner; "Wire Age," A. H. Hoffman; "Stray Currents," C. J. Snyder; "Converters," Fritz Bernick. A number of invited guests from the faculty were present, among them being President and Mrs. Storms and Dean and Mrs. Marston.

The final meeting of the Branch for the school year was held on May 19, and was devoted to the reading and accepting of reports of committees and the secretary. This was followed by the election of officers for the coming year. The officers elected were: Professor F. A. Fish, chairman; Professor Adolph Shane, secretary. Messrs. R. B. Gray, Ralph Chatterton, and G. B. Johnson were elected members of the executive committee.

KANSAS STATE AGRICULTURAL COLLEGE BRANCH

The Kansas State Agricultural College Branch held its regular meeting on May 4, 1909. The program consisted of an informal talk by Mr. Howard Campbell, superintendent of the electric inspection department of the Kansas Fire Inspection Office. Twenty-three members of the Branch were present.

The annual meeting of the Branch was held on June 8. The following officers were elected for the ensuing year: Chairman, Roy Wilkins; secretary, B. F. Eyer. The election of officers was followed by a talk and a demonstration by Messrs. E. C. Reed and E. W. Jones, on "Illumination and the Use of the Luminometer."

In order that the members could hear Mr. George T. Fielding, Jr., of the General Electric Company, a special meeting was held on June 10, at which there was a total attendance of 62 members and visitors. Mr. Fielding gave a talk on High-Voltage Power Transmission in America and Southern Europe."

LEWIS INSTITUTE BRANCH

A meeting of the Lewis Institute Branch was held on May 11, 1909, with Mr. R M. Walker presiding, and a total attendance of 300. An interesting lecture on "Zero Methods in Commercial Testing Applied to Telephone Apparatus," was delivered by Mr. J. Blaine Replogle, of the Western Electric Company, Chicago. Mr. Replogle discussed commercial methods of testing electrical apparatus, and carefully pointed out the possibility of error in testing due to poor contacts and inability to read graduated scales. Some of the improved methods of testing telephone apparatus were shown by means of lantern slides. An example of the perfection of such testing apparatus was a device used to determine the specific resistance of dry cell carbons. No graduating scales were read, the resistance being determined by the direction of swing of the galvanometer needle. It was stated that by this device an inexperienced man can test 5,000 carbons per day with an error of a small fraction of one per cent. Numerous other devices were described, in each case the final reading being determined by the direction of swing of the needle.

The concluding meeting of the season was held by the Branch in the Lewis Institute auditorium on May 26. The program opened with the annual dinner, which was attended by 80 members and students. Then followed addresses by the retiring officers, and the election of officers for the ensuing year. Those elected were: president, Mr. Frank Burch; vice-president, Mr. Melrose G. Kopf; secretary and treasurer, Mr. A. H. Fensholt. At the conclusion of the dinner and the executive business an illustrated lecture was delivered by Mr. Frank L. Perry, on "The Wright Aeroplane as a Basis for Wireless Telegraphy." Mr. Perry narrated his experience at the government trials of the Wright aeroplane conducted by Orville Wright at Fort Myer last September. The construction and operation of the machine were shown by means of lantern slides and models. The method of maintaining the equilibrium of the aeroplane by the simultaneous warping of the planes and the turning of the rudder was described in detail. The starting of the engine and the speed necessary for successful flight were also demonstrated. Wireless telegraph instruments were connected to the models, and the possibility of utilizing the aeroplane in wireless operations was shown. The lecture was concluded by throwing on the screen a series of moving pictures showing a number of actual flights made by Wilbur Wright in France. A series of starts, flying close to the ground, passing over balloons 100 feet above the ground, soaring at a height of 300 feet, and ultimately alighting safely on the ground at a predetermined spot were thus illustrated. The pictures showed the graceful maneuvering of the Wright aeroplane in dips and curves, and its steady behavior throughout its entire flight. The lecture was attended by 400 members, students, and visitors.

MEXICO SECTION

This Section held its regular meeting at the American Club on June 18. Mr. T. A. Worcester, of the General Electric Company, Schenectady, was the guest of the Section at this meeting. Mr. Worcester gave a talk on "Recent Developments in Lightning-Arresters." He gave several demonstrations with aluminum type arresters. There was an attendance of 25 members.

UNIVERSITY OF MICHIGAN BRANCH

At the meeting of this Branch held on May 26, 1909, Professor C. L. de Muralt presented a paper on "The Choice of a System of Electrification for Trunk Lines." The meeting was the most successful held during the season, and the attendance was unusually large, 152 members and visitors being present. Among those who took part in the discussion were: Professor G. W. Patterson Mr. McOmber, Mr. Shackelton, Mr. Witmore, and Professor Sawyer of the Michigan Agricultural College

NORFOLK SECTION

The May meeting of the Norfolk Section was held in the rooms of the Board of Trade on May 27, at which Mr. Carlyle J. Stephens gave a lecture on "Transformer Connections." No meeting was held in April.

PURDUE UNIVERSITY BRANCH

A meeting of this Branch was held on May 11, about 20 members being present. The subject for the evening was a paper by Mr. H. J. Muhleman, entitled " Description and Discussion of Test of Wabash Water and Light Plant."

Twenty-five members attended the meeting held on May 26. At this meeting Mr. C. E. Schutt presented a paper on " The Business and Profession of Engineering."

SAN FRANCISCO SECTION

At the regular monthly meeting of the San Francisco Section, held in the building of the Pacific Gas & Electric Company on Friday, June 25, 1909, Chairman Burkett announced the result of the election of members on the executive committee. This was the first election held in accordance with the provisions of the Section's new by-laws. Messrs. C. W. Burkett and S. J. Lisberger were elected for the two-year term, and Messrs. George R. Murphy, Wynn Meredith, and H. W. Clapp were elected for the one-year term, to commence August 1, 1909.

Mr. Elam Miller read a paper on the subject of electrolysis troubles encountered on underground telephone systems. Mr. W. J. Vincent gave a short talk on the troubles arising from electrolysis of gas and water pipes. Mr. S. B. McMeen gave a general talk on the subject of electrolysis and its causes. A number of interesting features were brought out in the discussion which followed. Fifty-one members were present.

SEATTLE SECTION

The regular monthly meeting of the Seattle Section was held in Science Hall, of the University of Washington, in order that Professor C. E. Magnusson could illustrate his paper on " Effects of Electrolysis on Reinforced Concrete," by exhibiting the results of tests made at the university. About 40 members and guests were present.

TORONTO SECTION

The Toronto Section held its final regular monthly meeting on April 23, 1909, with Mr. W. A. Bucke in the chair, and a total attendance of 115. The meeting was preceded by an informal luncheon at the St. Charles Café, which was attended by a large number of the members and their friends. Mr. Alex Dow, of Detroit, Mich., was the guest of the Section on the occasion of this meeting, and presented a paper on " Underground Cable and Conduits." Mr. Dow's talk was in the nature of a historic resumé of the development of underground transmission. He related various experiences of his own in connection with this work, and discussed it generally from its early history to the present state of the art. A somewhat lengthy discussion concluded the program, the following men taking part: Messrs. Bucke, Black, Ashworth, Mudge, and Aitken.

URBANA SECTION

The regular monthly meeting of the Urbana Section was held on May 28, 1909, with a total attendance of 43. Mr. V. A. Fynn, of St. Louis, Mo., presented a paper on " Alternating-Current Commutator Motors."

WASHINGTON SECTION

The annual business meeting of the Washington Section was held on May 26, 1909. The chief business discussed was the advisability of disbanding the Section, or the discontinuance of holding regular meetings. The meeting was addressed by Mr. Ralph W. Pope, secretary of the Institute, who expressed the hope that the Section would continue to exist and hold regular meetings. Mr. Pope also spoke on the work of the Sections in general, and mentioned many of the advantages of sectionalization both to the Institute as a whole and to individual members. Others spoke in favor of continuing the Section, and it was unanimously agreed to do so. The following officers were elected for the coming year: Chairman, Philander Betts; secretary, M. G. Lloyd; Executive Committee, Messrs. P. G. Burton, J. H. Hanna, P. B. Lamberton, George O. Squiers, H. B. Stabler.

Massachusetts Institute of Technology

Dr. Harold Pender has been appointed professor of theoretical and applied electricity, at the Massachusetts Institute of Technology. Dr. Pender is a graduate of Johns Hopkins University and took the degree of Ph. D. at that University in 1901 under the direction of Professor Rowland. His work in mathematical and experimental physics is recognized as notable. His teaching at the Institute of Technology will consist of a course for third-year undergraduate students and courses for graduate students in the more advanced theories of electric current flow and the electric transmission of power, in addition to the direction of experimental research by advanced students.

Forty per cent of the students just graduated from the electrical engineering course at the Massachusetts Institute of Technology had previously received the degrees of bachelor of arts or bachelor of science conferred, as a rule, in classical or literary courses. These men are going into a wide variety of activities, from the manufacture of electric instruments and of incandescent lamps to electric transmission of power and heavy electric traction.

Cornell University

The forty-first annual commencement was held on Thursday, June 17. In the absence of President Schurman, degrees were conferred by Professor T. F. Crane, who retires this year from the head of the department of romance languages. More than 225 men received the degree of mechanical engineer, including about 75 who have specialized in electrical engineering.

Two years ago the electrical course was improved by the addition of a junior laboratory course. The present class is the first to graduate with this complete course; namely eight hours of required electrical work in the junior year and twenty hours in the senior year. This complete course comprises: 1. A junior laboratory course with one experiment per week throughout the year; 2. A senior laboratory course with two experiments and one recitation per week throughout the year; 3. A junior recitation course on the elements of electrical engineering with two recitations per week throughout the year; 4. A senior recitation course on the theory of electric circuits and machines with two recitations per week throughout the year; 5. A senior problem course with two computing periods per week throughout the year. In addition a number of elective courses were offered, one or more of which were taken by the electrical seniors.

The benefit of the junior introductory courses in preparing seniors to attack electrical problems has been clearly shown this year. The senior problems form the main portion of the course. They consist in the prediction of the performance of electric circuits and machines when the dimensions of the various parts and the properties of the materials are given. In order to make such calculations the student must be familiar with the theory and the operation of the electrical device studied. The solution of these problems prepares students also to take advantage of the advanced courses offered during the second term. By means of these courses a student may follow out any particular inclination toward a special electrical subject. While these courses are of a somewhat practical nature the theory is not forgotten. The courses are not intended to fit students directly for practical work, but rather to show the application of electrical principles to particular fields.

A Valuable Report on Smokeless Coal Combustion

" The Smokeless Combustion of Coal in Boiler Plants " is the title of a bulletin recently issued by the Technologic Branch of the United States Geological Survey. Various types of boiler settings and stokers are discussed in their relation to smokeless combustion of coal, and voluminous data are given as to the kind and character of the coal used. A concluding chapter gives valuable information regarding the operation of central heating plants. The bulletin may be obtained by writing the U. S. Geological Survey at Washington, D. C.

The book departments of the McGraw Publishing Company and the Hill Publishing Company have consolidated under the corporate name of the McGraw-Hill Book Company with offices after July 1, at 239 West 39th Street, New York. The officers of the new company are: president, John A. Hill; vice-president, James H. McGraw; treasurer, Edward Caldwell; secretary, Martin M. Foss.

Personal

Mr. Moncure C. Carpender has been appointed general manager of the Plattsburgh Traction Company, Plattsburgh, N. Y.

Mr. E. W. Farley has left the Schenectady works to become general supervisor of maintenance, American Locomotive Company, New York City.

Mr. H. R. Stuart has been transferred from the Great Lakes region to the superintendency of the Radio Telephone Company's factory at Newark, N. J.

Mr. H. E. Oskamp, formerly located at Rochester, N. Y., is now in charge of the main office of the Fillmore Machinery Company, 512 Race Street, Cincinnati, Ohio.

Mr. F. W. Field until recently a student at the University of Iowa, Ames, Iowa, has entered the employ of the Chicago Telephone Company, Chicago, Illinois.

Mr. O. I. Eberhardt, formerly with the Westinghouse Electric & Manufacturing Company, Hazelton, Pa., has been transferred to the company's Wilkes-Barre, Pa. office.

Mr. H. F. Way, recently associated with the Dunedin New Zealand hydroelectric installation, has entered the construction department of the Lakima Valley Power Company.

Mr. George W. Cravens, consulting engineer, of Chicago, Ill., announces the removal of his office to the First National Bank Building, where he will have larger quarters.

Mr. Harry H. Knox has left the John J. Sesnon Company, of Nome, Alaska, to accept the position of manager of the Alaska Electric Consolidated Company, Cordova, Alaska.

Mr. Cale R. Gough, formerly western editor of the Street Railway Journal, at Chicago, is now at Lawrenceville, Ill., as manager of the Lawrenceville Light and Water Company.

Mr. E. L. West, formerly assistant engineering manager of J. G. White and Company has been appointed assistant general manager of the Central Colorado Power Company, Denver, Colorado.

A. S. Langsdorf of St. Louis, who will be at Bald Eagle, Minn., unt September 1, has practically recovered from the injury to his shoulder which forced him to withdraw from the baseball game at the Frontenac convention.

Mr. David D. Gibson, formerly engineer with Lyde & Kyser of Birmingham, Ala., has accepted position as assistant superintendent of shops with the Great Falls and Old Dominion Railroad Company at Rosslyn, Va.

Mr. W. R. Thompson has resigned as acting electrical engineer of the Public Service Commission, First District New York, to become assistant chief engineer of H. M. Byllesby & Company, Chicago, Illinois.

Mr. Ray D. Lillibridge has removed from 170 Broadway to 100 Broadway, New York City. Associated with Mr. Lillibridge is Mr. William L. Rickard. They will conduct a technical publicity business.

Mr. Walter G. Clark, president of the Parker-Clark Electric Company, has given up his offices at 135 Broadway, New York City, and taken a suite in the tower of the Singer Building, 149 Broadway.

Mr. Charles S. Ruffner, who was engineer-in-charge with the Telluride Power Company, is now superintendent of operation of the Central Colorado Power Company, with headquarters in Denver, Colo.

Mr. E.W.P. Smith, formerly with the Pike's Peak Hydroelectric Company, Manitou, Colo., has entered the employ of the Westinghouse Electric & Manufacturing Company, as an engineering apprentice.

Mr. O. C. Hovland recently resigned his position as installer for the Automatic Electric Company, of Chicago, to associate himself with the Hovland Manufacturing Company, at Minneapolis, Minn.

Mr. J. A. Simpson, who until recently was district engineer with the New York and New Jersey Telephone Company, at Newark, N. J., is now employed in the milling department of the Taylor Gold Mining Company, Magnolia, Colo.

Mr. James A. Sharp, formerly traveling demonstrator and salesman for the Lineman Protector Company, of Detroit is now connected with the Sanitary District of Chicago. His address is 143 South Western Avenue.

Mr. E. R. Douglas has resigned his position as superintendent with Adriance, Platt & Company, Poughkeepsie, N. Y., to accept the appointment of works-manager for the Hero Fruit Jar Company, Philadelphia, Pa.

Mr. Edward P. Decker, who for the last 10 years has been associated with Westinghouse, Church, Kerr & Company, as construction engineer, has entered the employ of the Kemiweld Can Company, Detroit, Mich., as manager.

Mr. S. R. Blakeman has returned to his home at Canton, Miss., having recently graduated from Purdue University, class of 1909. For the last three years Mr. Blakeman has been connected with the Canton Electric Light & Water Works.

Mr. W. E. V. Shaw having graduated from the Faculty of Applied Science, University of Toronto, is now electrical inspecting engineer with the Hydroelectric Power Commission of Ontario, Continental Life Building, Toronto, Ont.

Mr. Alfred G. Potts, who recently left the employ of the Denver & Interurban Railroad Company, Denver, Colo., is now connected with the Salt Lake City branch of Fairbanks, Morse & Company, as engineer-salesman.

Mr. S. N. Castle, who for some years has been employed as an engineer in the construction department of the Allis-Chalmers Company, New York district, has recently entered the turbine department of the General Electric Company, Lynn, Mass.

Mr. W. J. Hammer represented the Institute on the occasion of the presentation of the gold medals of the Aero Club of America to Messrs. Wilbur and Orville Wright by President Taft in the East Room of the White House on June 10, 1909.

Mr. Henry Floy has been retained by Mr. Bion J. Arnold in direct charge of the appraisal of the street railways in Greater New York and the elevated railways in Brooklyn, which Mr. Arnold is making for the Public Service Commission, First District.

Mr. Andrew Pinkerton has accepted a position on the staff of the American Sheet and Tin Plate Company, Pittsburgh, Pa., as electrical engineer. Mr. Pinkerton is in special charge of the manufacture of sheet steel for use in electrical machinery.

Mr. H. A. Tedman has severed his connection with the Eastern Electric Company of Boston, as manager of the Minneapolis office, and has accepted a position with the Muldoon Mining Company, of Hailey, Idaho, as electrical engineer in charge.

Mr. E. I. Dyer, who until recently was manager for Charles C. Moore & Company, Seattle, Wash., has resigned that position to accept one as engineer in the manufacturing department of the Union Oil Company, 233 Mills Building, San Francisco, Cal.

Dr. J. Franklin Meyer, formerly professor of physics at the Pennsylvania State College, State College, Pa., has resigned his professorship to accept a position with the Westinghouse Lamp Company, Bloomfield, N. J., in charge of the physical research.

Mr. J. Hanson Boyden has formed a partnership with Mr. Robert Watson, under the firm name of Watson & Boyden, for the practice of patent law and patent soliciting, with offices in the National Union Building, 918 F Street, N. W., Washington, D. C.

Mr. L. O. Veser has resigned the position of electrical superintendent with the H. E. Talbott Company, of Brownsville, Pa., to take charge of some special power transmission work with the Mahoning & Shenango Railway and Light Company, of Youngstown, O.

Mr. C. B. Cook has been placed in charge of a newly opened sub-office of the Cleveland district office of the Allis-Chalmers Company, in the Ohio Building, Toledo, O. All of the company's business in northwestern Ohio will be transacted through the Toledo office.

Mr. Franz J. Dommerque has resigned as secretary of the Kellogg Switchboard and Supply Company to become general representative of the Stromberg-Carlson Telephone Manufacturing Company. He will also act in an advisory capacity on factory matters.

Mr. L. J. Flint has accepted the presidency of the P. & F. Electric Company, Old Colony Building, Chicago, Ill. The company will carry on a general consulting and development business in electrical lines. Mr. Flint was formerly engineer of inspection with the Kellogg Switchboard and Supply Company, of Chicago.

Mr. Oddgeir Stephenson, of St. Louis, Mo., has been appointed by President Ferguson, a delegate of the Institute to the Congress of the International Association for Testing Materials, to be held in Copenhagen, Denmark, September 7 to 11, 1909. Mr. Stephenson is a graduate of the University of Copenhagen.

Mr. Philip S. Biegler has resigned his position as assistant professor of electrical engineering at the State University of Iowa, to enter the firm of Baender & Biegler, Spokane, Wash. Mr. F. G. Baender was formerly assistant professor of mechanical engineering at the University of Iowa.

Mr. H. H. Sinclair, who for the last 18 years has been connected with the electric interests of Southern California, has been appointed vice-president and general manager of the Great Western Power Company, with headquarters at San Francisco, Cal. Mr. Sinclair took charge on June 1, 1909.

Mr. Leopold Stocker, master electrician, Signal Corps, U. S. A., who has been on duty in San Francisco, Cal., in connection with the fire control installation work in that city, has been assigned to duty in the Signal Corps section of the War Department exhibit at the Alaska-Yukon-Pacific Exposition, Seattle, Wash.

Mr. Frank H. Abbey, for the last three years mechanical engineer and salesman for the Gifford-Wood Company, and located at Hudson, N. Y., has been placed in charge of the ice, coal and general conveying machinery branches of that company's business, with headquarters at its Arlington, Mass., plant.

Mr. W. B. Gump, formerly of Los Angeles, Cal., has accepted the position of designing electrical engineer for the Nisqually power development, of Tacoma, Wash. This develpoment contemplates a completely new generating station 35 miles from Tacoma, and a sub-station will be located in the city for local distribution.

Mr. Philip G. Gossler has resigned the vice-presidency of the J. G. White Company and is now associated with the banking house of A. B. Leach & Company, New York City, in a special consulting and administrative capacity. Mr. Gossler will continue his connection with the J. G. White Company and various other properties as director.

Mr. C. R. McKay has resigned his position as manager of the light and power department of the Toledo Railways and Light Company, Toledo, O., to become general manager of the Union Light, Heat, and Power Company and the South Covington and Cincinnati Street Railway Company with headquarters at Covington, Ky.

Robert H. McKibben, formerly chief electrician for the Palmer Mountain Tunnel and Power Company, of Loomis, Wash., is now with the New England Fish Company, installing a 1,200 kw. hydroelectric plant at Ketchikan, Alaska. Mr. McKibben will retain his connection with the company at Ketchikan as their electrical engineer for an indefinite period.

Mr. P. G. Schwarz, after completing the installation of the New Bremen Municipal Light & Water Plant, New Bremen, O., has resigned his office of superintendent, and accepted a position in the engineering department of Fairbanks, Morse & Company, Cincinnati, O. Mr. Schwarz will devote most of his time to electrical developments at that office.

Mr. Alfred E. Seeling has been appointed general inspector for the Connecticut River Transmission Company and will have charge of the meter instrument and testing departments of that company. Mr. Seeling formerly had charge, under Professor George F. Sever, of the electric meter testing which Columbia University is doing for the Department of Water Supply, Gas and Electricity, New York City.

Mr. J. F. Geiser, recently associated with the Waynesboro Electric Light and Power Company, and the Chambersburg Greencastle & Waynesboro Street Railway Company, has severed his active connection with these companies to accept the positions of secretary, general manager, and electrical engineer of the Carbon Transit Company of Mauch Chunk, Pa.

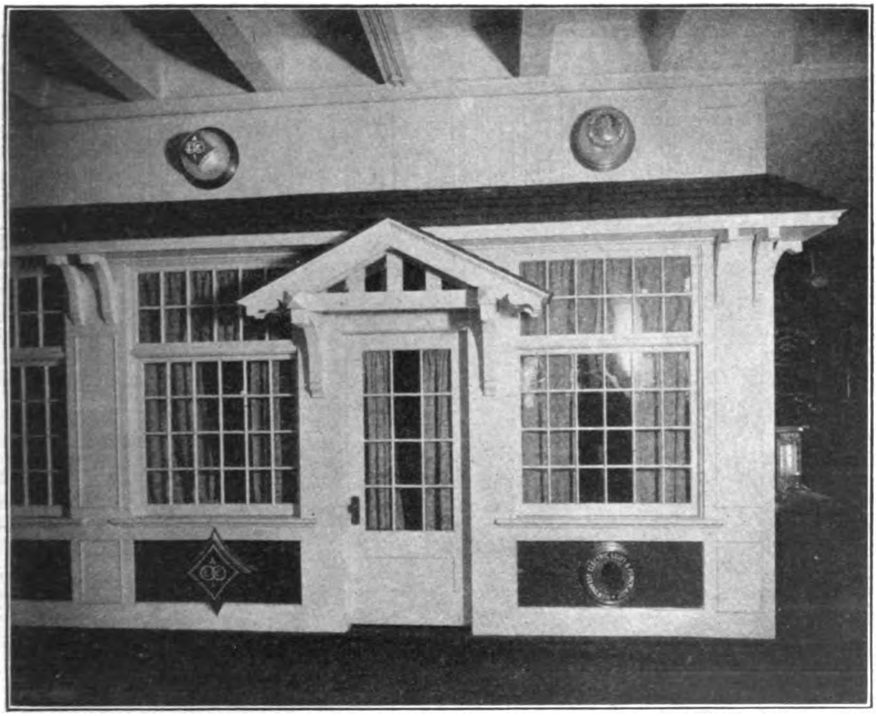
Mr. J. M. Jolly, who for nearly eight years was associated with the Westinghouse interests in Australia, has recently been appointed to sole charge of the Allegemeine Elektricitats Gesselchaft's representation in Australia, excepting western Australia. Prior to taking up his new duties Mr. Jolly spent some months at the company's works in Berlin. His headquarters are in Melbourne.

Mr. Edwin A. Taylor, for the last four years with A. H. Bickmore & Company, New York City, is now assistant engineer in charge of field work on the Nisqually power plant, Tacoma, Wash. This hydroelectric plant is to be built by the city of Tacoma on the Nisqually River about 35 miles south of the city. Under a head of over 400 ft. the plant will develop about 20,000 h.p. The estimated cost is $2,000,000.

In the personal notes appearing in the July issue it was erroneously stated that Mr. Ernest J. Berg, who was recently awarded the degree of D. Sc. at the 113th commencement exercises at Union University, Schenectady, N. Y., was a graduate of the University of Stockholm. Mr. Berg is a graduate of the Royal Technicum, Stockholm.

Institute Quarters at the A. Y. P. Exposition, Seattle

September 7, 8, and 9 have been designated as electrical days, by the management of the Alaska-Yukon-Pacific Exposition at Seattle. Meetings of the Seattle Section and the Northwest Electric Light and Power Association will be held on those dates, and members or their friends who expect to visit the exposition should endeavor to be there at that time. Papers or addresses by Eastern and Pacific Coast members will be especially welcome. The joint booth for the two societies is now finished, with a young woman in charge, who will provide all necessary information. A full supply of Institute literature is available and visitors will be expected to register their names with home and local addresses. The booth will be open week-days during the entire period of the exposition.



Exterior of quarters of the Seattle Section and the Northwestern Electric Light & Power Association at the A. Y. P. Exposition, Seattle, Wash., 1909

The Hudson-Fulton Celebration

For eight nights during the Hudson-Fulton Celebration this autumn New York in all its boroughs will be brilliantly illuminated. The illumination will begin every night at 6:30 and continue until 12:30 a.m.

Conservative estimates place the number of lights to be used, in addition to the regular lighting of the city, at between 1,000,000 and 1,500,000 incandescents; 7,000 arc lights, 3,000 flare arcs, one battery of 4 search lights of 100,000 c-p. each, and one battery of 12 search lights aggregating 1,700,000 c-p., a total of approximately 26,260,000 c-p.

One of the features of the illumination in New York will probably be the use of the immense battery of searchlights to be located on Riverside Drive at 110th Street. This searchlight battery will be first put in operation on the night of Saturday September 25 and continue until the end of the celebration. It will make the river as light as day for miles each way. When brought together in a single beam as it will be on the night of October 9, it can be seen for 50 miles.

Interior of quarters of the Seattle Section and the Northwestern Electric Light & Power Association at the A. Y. P. Exposition, Seattle, Wash., 1909

On the evening of Saturday, September 25 with thirty or forty foreign and American war ships anchored off 110th Street, a grand fireworks display will be given on floats on the New Jersey side of the river in honor of the visiting vessels.

The Illumination Committee have practically determined the locations for the signal fires up the Hudson River between New York City and Newburgh in connection with the scheme for illuminating the entire river front on Saturday night, October 9, which will be known as Illumination night. Subject to change, the points selected are as follows:—Governors Island, Fort Lee, Fort Washington, Spuyten Duyvil, Alpine, Hastings Point, Staten Island, Hook Mountain, High Tor, Stony Point, Dunderburgh, Anthonys Nose, Sugar Loaf Hill, West Point, Constitution Island, Storm King, Bull Hill, and Crows Nest. On each of these prominent points an immense signal fire will be constructed which will burn thirty feet high for four hours. These fires and also all those near and beyond Newburgh to Albany will be started on telegraphic signal by President Taft. Signal rockets, bombs and a large display of such fireworks will be kept in operation throughout the evening.

Tenants and Meetings in the Engineers' Building, New York During 1908

In petitioning for the placing of a station on the proposed extension of the McAdoo underground railroad at 39th Street and Sixth Avenue, New York, the secretary of the United Engineering Society, Mr. F. R. Hutton, prepared the following details of occupancy of the building and attendance at various meetings held in the building during the year 1908.

List of societies occupying offices in the Engineers' Building and statement of membership, January 1, 1909.

Society.	*Membership.*
American Society of Mechanical Engineers	3,800
American Institute of Electrical Engineers	6,400
American Institute of Mining Engineers..	4,300
N. Y. Electrical Society..................	950
American Gas Institute..................	1,300
N. Y. State Association Opposed to Woman Suffrage.....................	2,000
Electrical Manufacturers Club...........	50
Wire Inspection Bureau................	24
Empire State Gas & Electric Association..	75
American Association of Electric Motor Manufacturers.....................	200
National Electric Light Association......	3,065
Museum of Safety & Sanitation..........	50
Boone & Crockett Club.................	173
Association of Edison Illuminating Companies..........................	68
Technical Society of New York..........	150
Explorers Club.........................	110
Society of Naval Architects & Marine Engineers..........................	870
American Street & Interurban Railway Association........................	1,000
Illuminating Engineering Society........	1,065
Municipal Engineers of City of New York.	565
Total........................	26,215

List of society meetings and actual attendance during the year 1908.

Society	*Meetings held.*	*Attendance.*
American Society of Mechanical Engineers...........................	14	5,393
American Institute of Electrical Engineers...........................	11	3,745
American Institute of Mining Engineers...........................	4	349
New York Electrical Society........	3	761
New York Railroad Club............	9	3,774
New York Telephone Society........	9	2,314
American Society of Heating and Ventilating Engineers............	3	364
Blue Room Engineering Society.....	12	415
Explorers Club.....................	9	472
German Scientific Club.............	3	183
Western Electric Club..............	5	507
Technical Society of New York.....	10	261
American Street & Interurban Railway Association.................	2	49
Municipal Engineers of New York...	9	1,404
Illuminating Engineering Society....	7	501
Society of Naval Architects & Marine Engineers......................	2	301
American Society of Refrigerating Engineers......................	3	291
Railway Signal Association..........	2	324
Cast Iron Fittings Manufacturers Association.......................	6	102
Underwriters Laboratories..........	1	12
Association of Edison Illuminating Companies......................	4	60
Empire State Gas & Electric Association...........................	5	134
United States Daughters of 1812....	1	405
Reed Hollow Earth Explorers Club..	1	84
New York Society of Accountants & Bookkeepers....................	27	827
Musurgia Society..................	1	688
New York Electrical Trade School..	1	262
American Electro-Therapeutic Association........................	8	850
American Gas Institute.............	3	1,344
American Society for Promotion of Industrial Education.............	1	203
American Railway Master Mechanics.	1	57
American Geographical Society......	2	801
New York State Association Opposed to Woman Suffrage..............	1	17
American Roentgen Ray Society....	6	430
Total.....................	186	27,684

Obituary

Mr. William Drayton Buckman, erecting engineer for the Westinghouse Electric and Manufacturing Company in its Philadelphia office was accidentally killed at Lancaster, Pa., on July 7, 1909, receiving an electric shock of 2300 volts while working on the back of a switchboard. Mr. Buckman was elected an Associate of the Institute on March 12, 1909. He was born at Philadelphia, Pa., March 10, 1882.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Best Type of Canal for Panama. (House Document no. 10, pt. 2). Washington, U. S. Government, 1909. (Gift.)

Gift of Edward Caldwell.

Applications of Electric Energy for Mining Uses by the Sprague Electric Railway & Motor Company. New York, 1890.

Electric Transmission of Power. (Catalogue A, Sprague Electric Railway & Motor Company.)

Electric Transmission of Power for Mining Work, "2-A." No place, no date.

Facts as to the Sprague Electric Motors. "5." No place, no date.

Instructions for Using Equalizing Coils on No. 6 Street Car Motors. (Edison General Electric Co.)

Motors for Stationary Work (Catalogue C, Sprague Electric Railway & Motor Company.)

One of the Practical Results of the Use of Sprague Motors "8." No place, no date.

Suspension Transportation by Electricity for Mining Work. "4-A." No place, no date.

Transmission of Power by Electricity. By F. J. Sprague. New York, 1887.

Electric Trades Association of the Pacific Coast. Annual Report, 7th San Francisco, 1909. (Gift.)

Electrical Trades' Directory and Handbook for 1908. London, "The Electrician" Printing & Publishing Co., 1908. (Purchase.)

Gatun Dam and Earth Dams in General. (House Document no. 10.) Washington, U. S. Government, 1909. (Gift.)

General Lectures on Electrical Engineering. Edition 2. By C. P. Steinmetz. Schenectady, Robson & Adee, 1908. (Gift of Publishers.)

L'Institut de France. 2 volumes. Par Gaston Darboux, Henry Roujon and Georges Picot. Paris, 1907. (Purchase.)

Leitfaden der Drahtlosen Telegraphie von J. Zenneck. Stuttgart, Enke, 1909. (Gift of Gesellschaft für Drahtlose Telegraphie, Berlin.)

List of Wireless Telegraph Stations of the World. Washington, U. S. Government, 1908. (Purchase.)

Lock Canal at Panama. (House Document no. 10, pt. 3.) By J. R. Freeman, Washington, U. S. Government, 1909. (Gift.)

Manual of Electrical Undertakings and Directory of Officials 1908. Volume 12. Compiled by Emile Garcke London, Electrical Press, Ltd., 1908. (Purchase.)

Massachusetts Gas Commissioners, Board of. Annual Report. 2d. Boston, Wright & Potter Printing Co., 1887. (Purchase.)

Montana State College of Agriculture and Mechanic Arts. Annual Catalogue. 16th, 1908–1909. Bozeman, 1909. (Gift.)

National Physical Laboratory. Collected Researches. Volume V, 1909. Teddington, 1909. (Exchange.)

——Report for the year 1908. Teddington, 1909. (Exchange.)

National Telephone Exchange Association. Proceedings volume 12, Brooklyn, 1890. (Purchase.)

National Telephone Journal. Volume 1, number 2-date. London, 1906-date. (Purchase.)

New York Electric Club. Papers Nos. 15–18, 20–27. New York, 1888–1891. (Purchase.)

New York State Water Supply Commission. Annual Report and Maps. 4th. Albany, J. B. Lyon, Company, 1909. (Gift of the State Water Supply Commission.)

Railway Statistics of the United States of America. 1908. Edition 2. Chicago, R. R. Donnelley & Sons Co., 1909. (Gift of S. Thompson.)

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*Deceased.

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Washington, D. C.	Apr. 9, '03	Philander Betts	M. G. Lloyd, Bureau of Standards, Washington, D.C.

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Colorado, Univ. of	Dec. 16, '04	H. H. Watters	L. D. Jones, Univ. of Colorado, Boulder, Colo.
Iowa State College	Apr. 15, '03	F. A. Fish	Adolph Shane, Iowa State College, Ames, Ia.
Iowa, Univ. of	May 18, '09		
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Kansas, Univ. of	Mar. 18, '08	Ray Jones	E. J. Thiele, 1042 Tennessee Street, Lawrence, Kan.
Lehigh University	Oct. 15, '02	W.W. Broadbend	Howard M. Fry, Lehigh University, Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	Frank Burch	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06		Gustav Wittig, Univ. of Maine, Orono, Me.
Michigan Univ. of	**Mar. 25, '04**	H. F. Baxter	P. R. Moffett, 1335 So. State St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw	H. D. Carpenter, Univ. of Missouri, Columbia, Mo.
Montana Agr. Col	May 21, '07	C. S. Kennedy	J. A. Thaler, Montana Agr. Col., Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse	V. L. Hollister, Station A, Lincoln, Neb.
New Hampshire Col	Feb. 19, '09	A. M. Buck	E. R. Fellows N. H. College, Durham, N. H.
Ohio State Univ	Dec. 20, '02	F. W. Funk	F. C. Caldwell, Ohio State Univ., Columbus O.
Oregon State Agr. Col	Mar. 24, '08	S. H. Graf	C. Christiansen State Agricultural College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	E. A. Wilcox	H. S Amer, Penn. State College, Pa.
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Worcester Poly. Inst	**Mar. 25, '04**	Ray H. Taber	Albert A. Nims, Worcester Poly. Inst., Worcester, Mass.

Total, 27

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

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THE EDITING COMMITTEE

GEORGE A. WARDLAW, Editor

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Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXVIII **September, 1909** No. 9

Transactions for 1908

Volume XXVII of the TRANSACTIONS for 1908, aggregating 1761 pages, is now at the bindery and will shortly be distributed among the Members and Associates that have paid their dues to May 1, 1909. Members and Associates in arrears for the time covered by these TRANSACTIONS are, in accordance with the Institute By-Laws, not entitled to receive this volume. Volume XXVII consists of two parts, designated respectively Part I and Part II. Part I, consisting of 844 pages, contains the papers and discussions from January 1 to the end of the morning session of June 30, 1908, at the Atlantic City convention. Part II, consisting of 917 pages, contains the papers and discussions from the beginning of the evening session of June 30, 1908, at the Atlantic City convention to December 31, 1908, the amended By-Laws adopted November 13, 1908, and the report of the Board of Directors for the fiscal year ending April 30, 1908.

Institute Committees

In accordance with Sections 41 and 46 of Article VII of the Constitution, at the meeting of the Board of Directors held August 13, 1909, President Stillwell announced his appointment of standing and special committees for the current administrative year expiring July 31, 1910. The nine regular Standing Committees appointed were: Finance, Library, Meetings and Papers, Editing, Board of Examiners, Sections, Standards, Code, and Law. The special committees are variable, and are appointed from time to time by the president. Ten special committees were appointed as follows: Railway, Educational, High-Tension Transmission, Industrial Power, Electric Lighting, Telegraphy and Telephony, Edison Medal, Membership, Conservation of Natural Resources, and Intermediate Grade of Membership. As provided for in Sec. 46, at President Stillwell's request the Board of Directors added auxiliary members to several of the standing committees. A new Executive Committee was also appointed. The selection of members to serve on these committees is a matter of vital importance to the welfare of the Institute, as the value of its work depends largely upon their activity and judgment.

Secretary's Western Tour

At the meeting held on August 13, 1909, the Board of Directors voted that Secretary Ralph W. Pope be delegated as a representative of the Institute to attend the National Conservation Congress at the Alaska-Yukon-Pacific Exposition, Seattle, August 26, 27, and 28, also the joint meeting of the Seattle Section with the Northwest Electric Light & Power Association, September 7, 8, and 9. Mr. Pope will then visit the Sections at Portland, San Francisco, and Los Angeles, and returning will stop at Salt Lake City, Provo, and Denver. An effort has been made to arrange meetings at each of these cities, in order to give Mr. Pope an opportunity locally to discuss Institute affairs. In the course of the trip he will meet as many Institute members as possible at each of these cities, and also any other electrical engineers who may be interested in the work of the Institute.

Minutes of Board of Directors Meeting

The regular monthly meeting of the Board of Directors was held at 33 West 39th Street, New York City, on Friday, August 13, 1909. The directors present at the meeting were: President Lewis B. Stillwell, New York; Vice-President Calvert Townley, New Haven, Conn.; Managers, P. H. Thomas, New York; W. G. Carlton, New York; Severn D. Sprong, New York; A. W. Berresford, Milwaukee, Wis.; Charles W. Stone, Schenectady, N. Y.; Treasurer George A. Hamilton, New York; and Secretary Ralph W. Pope, New York. The following 28 Associates were elected:

BAKER, LINNAEUS EARL, Partner, The Inland Machinery & Engineering Co., 615 Jamison Bldg., Spokane, Wash.

CHAMPLIN, ERI ADDISON, 1st Class Electrical Draftsman, Dept. of Yards & Docks, U. S. Navy Yard, Boston, Mass.

COONS, JAMES W., Station Construction Foreman, Pacific Gas & Electric Co.; res., 2006 Cedar Street, Berkeley, Cal.

CROWLEY, JOHN WASHINGTON, Salesman, Westinghouse Electric & Mfg. Co., res., 3015 W. North Ave., Baltimore, Md.

DEAN, WILLIAM M., Constructing Engineer, B. F. Kierulff, Jr. & Co., res., 910 W. Third St., Los Angeles, Cal.

DEMKE, ALBERT H., Chief Inspector, Home Telephone Company; res., 346 Clay St., Portland, Ore.

EDGAR, GEORGE THOMAS, Chief Draftsman, with E. E. Stark, Dunedin City Corporation, Market Street, Dunedin, N. Z.

FLOWER, GEORGE H., Chief Engineer, H. W. Corbett Estate, 710 Corbett Bldg., Portland, Oregon.

FREYGANG, PAUL J., Electrical Inspector, North Shore Electric Co.; res, 92 East 17th Street, Chicago, Ill.

HANNAFORD, FOSTER, Apprentice, Westinghouse Electric & Mfg. Co.; Pittsburg; res., Gray Bldg., Wilkinsburg, Pa.

HEATHER, AUBREY GEORGE FORSTER, Meter Engineer, The Victoria Falls & Transvaal Power Co., Ltd., Transvaal, S. A.

HEILBRUN, RICHARD LUDWIG, Electrical Engineer, Allgemeine Electricictats Gesellschaft, Friedrichkarl Ufer 2/4, Berlin, N. W., Germany.

HOFINGA, D. H. J., Electrician, Butterick Publishing Co., Spring & Macdougall Sts., New York City.

JOHNSON, ORAL D., District Traffic Chief, Pacific Tel. & Tel. Co., Los Angeles, Cal.

KENLY, EDWARD MARION, Chief Engineer, Yakima Valley Transportation Co., Yakima, Wash.

KIRKPATRICK, CHARLES M., Detail & Supply Correspondent, Westinghouse Electric & Mfg. Co., 165 Broadway, N. Y. City.

McCULLOCH, JOHN FREDERIC, Consulting Engineer, Davenport Maquoketa & Dubuque Interurban Ry., Maquoketa, Iowa.

McGIRR, CHARLES H., Chief Engineer, Wells Fargo & Company Building, Portland, Ore.

MATSUKAWA, YUZO, Electrical Engineer, Shibaura Engineering Works & Co., Tokyo, Japan.

MORGANTHALER, PETER CORNELL, Engineer, Meter and Instrument Dept., Fort Wayne Electric Works, Fort Wayne, Indiana.

NISSEN, CHARLES MATHIAS, Associate Patent Lawyer, Brown & Hopkins, 1124 Monadnock Bldg., Chicago, Ill.

MAHONEY, FRANCIS WATSON, Electrical Engineer, Taunton, New Bedford Copper Co., Taunton, Mass.

PORTER, WILLIAM J. D. A., Asst. General Manager, Utica Gas & Electric Co.; res., 86 Lafayette St., Utica, N Y.

SPITZER, BENJAMIN, 165 East 95th Street, New York City.

Starmer, Frank Arley, Sub Station Foreman, Pacific Gas & Elec. Co.; 1248 Telegraph Ave., Oakland, Cal.

Trennert, Robert Fredrick, Los Angeles Aqueduct, Pinchot, California.

Welch, Geoffrey Wheaton, Tester, Edison Elec. Ill. Co. of Boston, 39 Boylston St., Boston, Mass.

Woods, Robert S., Electrician, Pacific Light & Power Co.; res., 919 S. Bonnie Brae, Los Angeles, California.

The following Associates were transferred to the grade of Member:

William Newton Ryerson, General Manager, Great Northern Power Co., Duluth, Minn.

John Castlereagh Parker, Mechanical and Electrical Engineer, Rochester N. Y.

Barzillai Gardner Worth, Electrical Engineer, Plainfield, N. J.

Walter J. Warder, Jr., Electrical Engineer, Roth Bros. & Company, Chicago, Ill.

Dudley Farrand, General Manager, E. E. Dep't., Public Service Corporation of New Jersey, Newark, N. J.

William Leslie Hooper, Professor of Electrical Engineering, Tuft's College, Mass.

At this meeting President Stillwell announced the appointment of the standing and special committees for the administration year beginning August 1, 1909. The personnel of these committees will be found elsewhere in this issue.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before October 1, 1909.

8806 Fligg, H. C., Denver, Colo.
8807 Hawley, K. A., Berkeley, Cal.
8808 Seshasayee, R., Trichinopoly, S. India.
8809 Robbins, A. H., Abington, Mass.
8810 Coxey, A. C., Crystal City, Mo.
8811 Carlton, R. H., Schenectady, N. Y.
8812 Moody, A. S., Seattle, Wash.
8813 Root, H. C., Fort Wayne, Ind.
8814 Orr, John, Johannesburg, S. A.
8815 Robinson, W., Brooklyn, N. Y.
8816 vonKrogh, K. K., Manchester, Eng.
8817 Montes, C. S., Camaguey, Cuba.
8818 Hoy, W. H., Toronto, Ont.
8819 Wilson, A. M., Lexington, Ky.
8820 Allen, W. D., Buffalo, N. Y.
8821 Carr, M. L., Chicago, Ill.
8822 Reed, J. E., Indiana Harbor, Ind.
8823 Merrill, W. L., Schenectady, N. Y.
8824 Wagley, O. O., Milwaukee, Wis.
8825 Kun, Emil, New York City.
8826 Morrell, H. H., Toronto, Can.
8827 Noggle, R. L., Minidoka, Idaho.
8828 Rasmussen, H. F. W., Lowell, Mass.
8829 Slocum, W. W., Pittsburgh, Pa.
8830 Vick, W. R., Santa Barbara, Cal.
8831 Barker, J. H., New York City.
8832 Kawado, Shuso, Shibaku, Japan.
8833 Saurman, A. B., San Francisco, Cal.
8834 Wall, S. S., Pulaski, Virginia.
8835 Noble, G. O., Los Angeles, Cal.
8836 Hutchinson, M. R., New York City
8837 Eckworth, F. C., Peterboro, Ont.
8838 Herrold, H. M., Pittsburgh, Pa.
8839 Jensen, Trygve, Urbana, Ill.
8840 Kohlhausen, B. F., Winchester, Va.
8841 Thompson, F. F , New Brunswick, N. J.
8842 Harmer, L. S., Merrill, Wis.

Total, 37.

Applications for Transfer

The following Associates were recommended for transfer by the Board of Examiners April 9, 1909. Any objection to these transfers should be filed at once with the Secretary.

Harry Milford Hope, Electrical Engineer, Stone & Webster Engineering Corporation, Boston, Mass.

Eugene Wilson Yearsley, Electrical Engineer, Midvale Steel Company, Midvale, Pa.

The Choice of a System of Electrification for Trunk Lines*

BY C. L. DE MURALT

In the paper here presented I shall discuss the electrification of only such roads as are now operated by steam. Street railways and light interurban railways present different problems and will not be considered.

Trunk lines handle two distinct kinds of traffic-passengers and freight. Each kind can again be subdivided into through and local traffic. It is quite probable that in the final outcome we will try to eliminate the subdivisions more or less. If we take, for instance, the various lines connecting Chicago with New York, it is possible that eventually there will be no great difference between the fine through trains and the poor local trains. The ideal would be to have a series of trains, each made up of, say, four or five cars, leaving New York at stated intervals and reaching Chicago at a definite time. These trains would stop only at a few intermediate stations such as Albany, Syracuse, Buffalo, Detroit, etc. Between these trains other trains would be made up in similar manner, but stopping at all the stations between the points just mentioned. Similarly in freight traffic; some freight trains would make few stops while others would make all stops. All passenger trains would be running at the same speed and all freight trains likewise. An interchange of passenger and freight would take place at the intermediate main stations. Think of the New York subway service and extend it to cover the distance between New York and Chicago, and to take in freight as well as passenger traffic, and you have what I have in mind as a possible final solution.

In the meantime, any electrification to be done in the next five years or so will probably be carried out on the plan of present steam service. There is no particular reason for revolutionizing trunk-line operation at this time. It will therefore be best simply to substitute electric locomotives for the present steam locomotives and operate all trains substantially as is done now. Suburban traffic in the large cities should preferably be handled by motor-car trains. This is a special kind of service, of relatively small importance when complete trunk-line electrification is considered, and therefore it may well be solved by a special method. The advantage of using motor cars for this kind of service lies principally in the high rate of acceleration made possible. By this method suburban trains can run on the same schedule speed as through trains, even though they make many more stops than the latter.

Any electric trunk-line equipment has three essential parts; power house, line equipment, and electric rolling stock. The last is of course the counterpart of the steam locomotives. The other two are not present with steam operation.

In the present state of the art four electric systems are suitable for electric trunk line purposes: 1. The direct-current system. 2. The single-phase alternating-current system. 3. The three-phase alternating-current system. 4. The combination system which uses single-phase alternating current on the line, converting on the locomotive into direct current for use in the motors.

It is probably easiest to compare the systems after investigating the relative merits of their separate parts. Starting with the power house, we find that all four systems use three-phase alternating-current generators. For the direct-current and the three-phase alternating-current systems this is literally true. The two single-phase alternating-current systems could use single-phase generators, but even they operate best if three-phase alternating current is generated in the power house and the three phases are used separately. There is thus no real difference in the type of generator used, nor need there be any difference in the cost per kilowatt of power-house capacity. The difference lies in the size of the power house required. All four systems will have to exert substantially the same power at the driving axles of the trains, but the losses between driving axles and power house vary with the different systems. The single-phase systems have the greatest losses and therefore require the largest power-house capacity for the same service. The three-phase system is the most efficient and therefore requires the least power-house capacity. Roughly speaking, for each 100 kw. in power house capacity which the direct-current system requires, the single-phase systems require about 180 kw. and the three-phase system about 70 kw.

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*A paper presented before the University of Michigan Branch, May 26, 1909.

As to the line equipment: we would better distinguish between the transmission line which carries the high-pressure current along the right-of-way; the sub-stations which transform the high pressure to medium pressure; and the contact line by means of which the medium-pressure current is transmitted to the locomotives. It is of course possible to combine all these three items into one by using the transmission line directly as a contact line, provided distances are not too great and traffic is not too heavy. With 10,000 volts, distances of 40 miles and even greater may thus be covered. The more locomotives on the road at the same time, the shorter would be this distance, due to the increased line drop.

But even with light traffic I see no advantage in feeding the contact line direct from the power house, as it necessarily multiplies power houses. On a 150-mile division there would be at least two or three power houses, all of medium size and therefore of low efficiency if compared with a single power house of a size suitable to feed the entire 150-mile division. There would also be more men required for the three small power houses than for the one large power house. Furthermore, it does not seem good practice to use the transmission line as a contact line, because the security of the service is thus undoubtedly lower than if separate contact and transmission lines were used, both being thoroughly sectionalized so that even in case of a breakdown current may be fed around the break and interruptions thus avoided. Everything considered, I believe that the use of an independent transmission line, with transformer sub-stations and an independent contact line, is by far the best arrangement.

With the transmission line we find essentially the same practice in all four systems. Here again, all preferably use three-phase alternating current, although for the two single-phase systems the three phases are used separately.

In the sub-stations the two single-phase systems and the three-phase system use transformers for reducing the high pressure of, say, 60,000 volts, to the medium contact-line pressure of, say, 3,000 to 15,000 volts. The direct-current system has to transform the high-pressure alternating current into medium-pressure direct current. This means that in addition to the transformers the direct-current system must use either synchronous converters or motor-generators, entailing an increase in first cost of installation as well as in cost of operation.

For the contact line we find that the most important point to be considered is the question of amount of current to be carried. An overhead contact-line can be made to give off only limited amounts of current. Depending on the speed of the locomotives, the amounts may be said to range somewhere between about 300 amperes and 600 amperes. A third rail can be used without difficulty for very much larger amounts of current. The locomotive power available is directly proportional to the product of amperes and volts. The higher the line pressure the lower the current for the same power. Whether or not an overhead contact-line can be used thus depends directly on the line pressure.

The alternating-current systems with pressures of 3000 volts and more have no difficulty in collecting the current by means of an overhead line. The direct-current system, which thus far has used 600 to 700 volts and is now using 1200 volts, is practically forced to use the third rail. If we go higher in direct-current pressure and use 2,000 volts or more, as is now customary in Europe, we may come back to the overhead line. There has been a great deal of discussion as to which type of contact line is better from the general operating standpoint, considering accidents, work of track gangs, etc. In actual practice it has been demonstrated clearly that there is little difference between the two types of contact lines from these viewpoints.

Let us finally investigate the question of electric rolling stock. We find that the direct-current motor was formerly considered to be the most desirable for trunk-line purposes. The principal reason for this belief was the fact that direct-current apparatus had been thoroughly developed and standardized in street-railway service and it was thus undoubtedly the most available when the first trunk-line electrifications were considered. Direct-current motors are mostly of the series type. Quite early in the art, shunt-type direct-current motors were experimented with. It was found, however, that for street-railway service—then the only kind of service considered—the shunt type was not advantageous. If direct current should be used extensively in trunk-line work, whether or not we may come back to the shunt type on account of its speed characteristics I do not know, but it is a possibility.

The single-phase alternating-current motor is really a direct-current motor which by certain refinements of construction has been made suitable for operation on alternating-current circuits. It is admittedly a makeshift, that is employed for the sole purpose of being able to use alternating currents in the contact line. Being a makeshift it naturally possesses a good many faults. For instance, the single-phase motor must use a much smaller flux density; hence its speed characteristics are very unstable. If single-phase and direct-current motors have the same current input for a certain speed, any increase in current due to greater power output will produce considerably more drop in speed in the single-phase motor than in the direct-current motor.

Furthermore, the single-phase motor has much larger copper losses; hence with a good starting torque a large amount of heat is produced. This is the explanation of the fact that single-phase motors cannot be used for starting heavy loads nor for starting light loads at frequent intervals. The single-phase motor is essentially a high-speed motor and is not suitable for frequent-stop service nor for heavy freight service. It can consistently be used for express work, since in this kind of service the trains can be started slowly and will run long distances at high speed.

The three-phase alternating-current motor is of a type quite different from either the direct-current or the single-phase motor. It is a constant-speed motor and has all the characteristics of the shunt type. The field strength is independent of the current flowing through the armature, and therefore the motor will maintain practically constant speed no matter what output it is called upon to give. This may be an advantage or a disadvantage according to circumstances. Not only will the motor run at practically constant speed, but from zero to full speed the rate of acceleration will be practically constant. The three-phase motor is thus able to accelerate much faster than either the direct-current or the single-phase alternating-current motor. Now, this may be considered a disadvantage where the stops are frequent, as in street-railway service, because the high rate of acceleration means a high peak.

It is an advantage wherever runs between stops are comparatively long, and, furthermore, where the highest schedule speed is desired. Constant speed in itself is an advantage because it insures maintenance of train schedule independently of the motorman's actions, of train weights, and of grades.

Perhaps the most important difference between the three types of motors lies in the ease with which they can get rid of the heat losses. The three-phase motor produces the greater part of its losses in the stationary or outside part of the motor. The losses in the direct-current and the single-phase motor are produced chiefly in the armature or rotating part and the heat must pass first through the field structure before it reaches the outside radiating surface of the motor. The winding of the three-phase motor, being evenly distributed, is much thinner than the winding of the direct-current or the single-phase motor. Therefore, the heat from the losses in the three-phase motor will reach the outside surface more easily. Moreover, the losses in the three-phase motor are smaller. It is not difficult to obtain 90 per cent efficiency in three-phase motors, while the efficiency of direct-current motors is somewhere between 75 and 85 per cent and that of single-phase motors is hardly better than 60 to 70 per cent.

For the foregoing reasons, if the motors are of the same size, the three-phase motor will run much cooler than the direct-current motor, and the latter much cooler than the single-phase motor; or if the same amount of heating is allowed for the three types, the three-phase motor will be much smaller than the direct-current motor and the latter much smaller than the single-phase motor for any given output. Of course this is a well-known fact thoroughly exemplified by stationary motor practice.

The difference in motor weight introduces differences in locomotive weights all the way through. To support a heavier motor requires a heavier frame. Actual locomotives plainly show this. The New Haven single-phase locomotive weighs 102.5 tons and produces 1000 h.p. at the usual 1-hr. rating. The New York Central direct-current locomotive weighs about 95 tons and produces 2200 h.p. on the 1-hr. rating. The Simplon three-phase locomotive weighs about 70 tons and produces 2700 h.p. on the 1-hr. rating. These figures correspond to about 200, 90, and 50 lb. per horse power, respectively.

It is the weight question that principally acts against the use of the fourth kind of electric system above referred to; namely, the converter locomotive. If single-phase alternating-current is converted on the locomotive into direct-current, the weight of the locomotive is increased by the weight of the converter and by the extra weight of mechanical parts to support the converter. Whether or not these converter locomotives weigh much more than single-phase locomotives remains an open question. It is a fact, however, that only a very limited number of converter locomotives—I believe not more than three—have thus far been built and all are used for experimental work.

After thus considering the three parts of electric trunk-line equipment—the power house, the line equipment, and the rolling stock—we can put the three parts together and determine the comparative advantages and disadvantages of the various systems taken as a whole. First let us establish the over-all efficiency for each system from power house to driving axle. Starting at the driving axle we find that the amounts of power required for hauling any given trailing load are different, following the differences in locomotive weights. The three-phase system, having the lightest locomotive will require the least total power, the direct-current system will require more power, and the single-phase systems still more. Due to its higher motor efficiency, we again find the three-phase locomotive in the lead, with the direct-current system second, and the single-phase systems in third place.

From the contact device to the substation it is not quite so easy to draw direct comparisons among the systems, because a great deal depends upon the amount of metal placed in the contact line. In actual practice maximum losses in third rails for direct-current are generally limited to 50 per cent, and in three-phase and single-phase overhead contact lines to 15 per cent. Average losses will be smaller, but about in the same ratio. In the substations we find that the efficiency of the transformers is considerably higher than the combined efficiency of the transformers and the converters. The main transmission lines being essentially the same in all cases, the transmission loss will be practically proportional to the amounts of power carried over the transmission line in each system. Combining all these efficiencies, we find the approximate relation already mentioned; namely, that for the same trailing loads the power-house output will be least for the three-phase system, more for the direct-current system, and most for the single-phase systems, about in the proportion of 70 to 100 to 180. These are of course approximate figures only, subject to changes according to train weights, speeds, and metal used in line equipment. The amounts of energy consumed throughout the year are approximately in the same ratio.

To produce figures for first cost of installation so that they will be applicable to any general case is almost impossible. It is essential that each case be studied on its own merits, and a comparison of costs should be based on actual figures obtained after designs for the three systems have been decided upon.

Nevertheless it is permissible to draw a few general conclusions. For instance, wherever traffic is dense and rolling stock plays a preponderant part as compared with line equipment, without question the single-phase systems will be most expensive. Whether the direct-current or the three-phase system is more suitable in such a case is somewhat doubtful, with the odds in favor of the three-phase system. When a line is very long and the traffic light, rolling stock is less important compared with line equipment; in this case it is possible that the direct-current system will be out of the question, due to the great cost of converter sub-stations. Whether the three-phase system or the single-phase system should be used in such a case must be carefully investigated. The single-phase line equipment may be cheaper, but the difference is small. The difference in rolling stock is always great. In most cases the three-phase system will be preferable. It requires a very long line combined with a very light traffic to show an advantage for the single-phase system. As a matter of fact, if the traffic dwindles to five or six trains a day, which is about the point where the single-phase system may show to advantage over the three-phase system, then it is generally found that steam operation is preferable to electric operation.

It is thus seen that for real trunk-line service the three-phase alternating-current system will be found best in almost all cases. But there are some disadvantages connected with the three-phase system. and it is well to have those in mind before making a definite decision. First, we have two overhead wires on any railroad equipped for the three-phase system. Two overhead wires are undoubtedly more complicated and less desirable than one overhead wire.' The question is, will this show itself in cost of operation. Fortunately it does not. It is more difficult to install two overhead wires, because at the switches it is necessary to have a short insulated portion, so that the two wires, which have a difference of potential between them, can be safely brought past each other. But this does not mean that current must be interrupted at the switches. Three-phase locomotives are usually equipped with two contact devices, one at each end, and one of them will always be able to draw current from both phases of the line. Once a double overhead-line equipment is suitably installed, it operates more easily than a single line, as the roller runs more steadily on two wires than on one. In Europe three-phase lines have been in use for more than 15 years and not only was their operation thoroughly satisfactory, but the line expenses were actually less than for similar direct-current or single-phase lines.

A second objection is the small air-gap used in three-phase motors. Years ago it was thought dangerous to use what is now considered quite standard in this respect. Air-gaps have been reduced in direct-current motors also, and designers of single-phase motors are certainly showing that they are not really afraid of small air-gaps. The point is this. If a small air-gap is used between stationary and revolving parts, it is necessary to be sure that the gap will remain constant regardless of wear or vibration. This is a question of size of bearings. In direct-current and single-phase motors the space available for bearings is limited and therefore small air-gaps might be dangerous. In three-phase induction motors there is ample room for sufficient bearings and with almost the entire length of the shaft available for bearing surface it would be easy to reduce the gap even below the $\frac{1}{16}$ in. now used.

As a third disadvantage it is frequently claimed that the three-phase locomotive possesses only one efficient speed. Those who make this claim do not seem to realize that the direct-current locomotive acts exactly like the three-phase locomotive in this respect. If either of these two locomotives have only one motor, then there is only one speed at which it can run without using resistances. No one has ever thought of calling the direct-current locomotive ineffective on this account. Why then should the matter be counted against the three-phase locomotive? Most locomotives have two or more motors and in that event, two, three, four and more speeds can be obtained at which the motors can run without resistance. The advantage of the three-phase motor lies in the fact that, whatever speed is chosen, it is a constant speed. The superintendent of motive power can decide at what speed he wants his locomotive to run and they will run at that speed no matter how heavy the train or how inexperienced the motorman.

We find, therefore, that the disadvantages claimed against the three-phase system are all negligible except that of two overhead wires. These remain a disadvantage from the designing engineer's standpoint because it is somewhat more difficult to lay out a complicated track system with two overhead wires. From the operating engineer's standpoint the three-phase system possesses no disadvantages. It is well to bear this clearly in mind.

For real trunk-line work we can choose the three-phase alternating-current system without hesitation. For the suburban traffic at the large city terminals of trunk lines we can use the three-phase system if we desire to do so, but the use of the direct-current system for this particular service presents the advantage that the multiple-unit train control has undoubtedly been developed more for the direct-current system than for the three-phase system. Suburban traffic is generally so dense that rolling stock is by far the greater part of the equipment required and it is quite feasible to pay somewhat more for line equipment without seriously affecting the total first cost of installation. Suburban zones may therefore be well provided with direct-current equipment for multiple-unit train operation. Suburban trains will then draw their energy from a third rail, supplying direct-current while the through or main trains will use a three-phase overhead line equipment. Both the third rail and the overhead line will be fed by common three-phase power houses, three-phase transmission lines, and three-phase transformers, the direct-current for the third rail being obtained by adding converters to the sub-stations for this specific purpose. For the single-phase alternating-current system I can find no suitable place in trunk-line operation. It can of course be used as heretofore on long lines of the interurban railway character. But three of these, among them the first and most important lines, have just decided to go back to the direct-current system. It would seem, therefore, that even for this purpose the single-phase system is not suitable.

DISCUSSION ON "THE CHOICE OF A SYSTEM OF ELECTRIFICATION FOR TRUNK LINES." UNIVERSITY OF MICHIGAN BRANCH, MAY 26, 1909.

G. W. PATTERSON: There is one detail in favor of the three-phase system which the speaker has not mentioned; namely, the question of roads with heavy grades where both direct-current and single-phase motors have to cut off power and use the brakes when going down hill, whereas the three-phase motor will automatically return power to the line, thus braking the train electrically and not only saving wear and tear on brake shoes, but also directly economizing energy. A shunt motor of the direct-current type would of course also return power to the line, and it is not improbable that some day it may be sufficiently improved to take its place in trunk-line service.

The two overhead wires, I think, most of us are willing to agree are more of a bugbear than they ought to be.

It has always seemed to me that the large sums already spent by the roads which have installed electric equipment for the terminals would not by any means be wasted should a change in system be found necessary when the electrification is extended to the trunk line. Most of the present power houses, transmission lines, etc. would be available in case of change to the three-phase system.

L. W. MCOMBER: There are one or two points which should be brought out in favor of the single-phase system. First, on the question of maintaining train schedules, I believe that a railway man will not think constant speed most desirable. There will be delays, etc., which will have to be made up. With the single-phase motor all one has to do is to " notch up " on the controller and increase the speed. The same process would apply for any voltage drop on the line. Secondly, as regards the use of single-phase motors with heavy trains, we all know of the Port Huron tunnel where 1,000-ton trains are hauled through the tunnel and up a 2.5-per cent grade. This has been going on for some time and there has not been an hour's delay due to the breakdown of any motor. The locomotives have large starting torques for the power taken. The motors heat up, as the speaker said, but this is taken care of by forced draft. The locomotives go up the grade at the slow speed of 10 miles an hour or less and yet no burn-out or overheating has occurred. It is true, we might call the single-phase motor a makeshift, but it is a very fair, if not a good makeshift for railway service. The commutation is now practically as good as for direct-current machines. In starting a train with single-phase motors a pulsating starting torque is obtained. Thus when the wheels slip they have a chance to grip the track between the points of maximum torque. I think with the author that the matter of small air-gap between armature and field can be handled with proper design.

A. R. SAWYER: Only one with considerable experience would be able to add much to the statements of the author. In reading the log of the New Haven railway, as recently discussed in New York, I was impressed with the necessity of going into this discussion unbiased. Rapid developments will probably bring about some radical changes in handling traffic, as the author suggested. Mr. Muralt seems to lay emphasis on through passenger service, but it seems to me to be a question whether the railroad companies can afford to undertake electrification specifically for this kind of traffic. I was surprised to hear of the small air-gap used in the three-phase induction motors. Compared with the old direct-current motors this is certainly a very great change.

W. J. **SHACKLETON**: I do not quite understand why the direct-current equipment is heavier than the three-phase equipment.

MR. WHITMORE: Would not the lesser weight of the three-phase locomotives give less weight on the drivers and therefore less draw-bar pull?

C. L. **DE MURALT**: I am glad that Professor Patterson brought up the point of returning energy by regenerative control, since on all roads with heavy grades this is a decided advantage of the three-phase system. Not only can the returned energy be made useful for hauling trains up the adjoining grades, and not only is there a material saving in wear and tear on brake shoes, but there is also a great reduction in wrecks, many of which are caused by overheated brake shoes and tires when heavy trains have to be let down long hills on the brakes.

Mr. McOmber's remarks about making up speed should be carefully considered. In actual practice we find that any given track will allow running at a certain maximum speed. No matter how many notches there may be beyond that speed, they cannot be used. If they cannot be used, no better speed is available for the single-phase system as compared with the three-phase system. Indeed, the latter possesses the advantage that it takes away from the motorman the possibility of running at higher speeds than the tracks permit. As regards starting torque, there is no question that large torque can be obtained from the single-phase motor, but it requires twice as large a locomotive, which means useless weight and investment.

It is the first time that I have heard the pulsating torque claimed as an advantage for the single-phase system. If this is carefully investigated it will be found that it is a disadvantage. It does not allow fully the adhesion weight to be utilized and if the single-phase motors allow a better grip on the track than three-phase or direct current motors, it is only at torques about one-third as large as the adhesion weight would otherwise allow. At best, large torque in single-phase motors can be obtained only by increased losses, which are more serious than Mr. McOmber thinks. The case of the Port Huron installation is an example. The 1000-ton trains could be handled with considerably lighter locomotives if the three-phase system were used, and three-phase locomotives could start these trains on the grade, while the single-phase locomotives cannot do this. The Port Huron motormen are forbidden to start on the grades, because their single-phase motors would burn out if they attempted to do it. The New Haven installation is another example. The New Haven single-phase locomotives are not allowed to start at the maximum rate of acceleration which their weight could allow, because also in this case the motors would burn out.

Answering Mr. Shackleton's inquiry as to difference in weights, let me say that it is the heating limit which decides the weight of a railway motor. The three-phase motor is the most efficient electric motor. Its losses being smaller, the heat produced by these losses is in itself smaller. In addition to this, due to the construction of the motor, this heat can be very readily dissipated. The three-phase motor is lighter than the direct-current motor, and the latter, as well as the single-phase motor, is also handicapped by the addition of a commutator which still further increases its weight, thus making up the differences of weight stated in the paper.

There has been brought out the very important point of the smallest feasible locomotive weight. It is principally a question of speed desired. To obtain a certain draw-bar pull it is necessary to have a certain minimum weight on the drivers. To obtain a certain speed it is necessary to have sufficient motor capacity. Horse-power equals speed in miles per hour, multiplied by draw-bar pull in pounds, divided by 375. For low speeds it is possible with any electric system to give sufficient motor capacity within the maximum locomotive weight. As the speed goes higher and higher, a point will be reached where the increase in motor capacity will bring the locomotive weight above the minimum and those systems having the heaviest motors will reach this point first. Taking figures mentioned in the paper for locomotive weights in pounds per horse power output it is possible to establish this limiting speed point for each one of the systems. So long as the speeds stay below the point, all systems are on the same basis. For higher speeds first the single-phase and then the direct-current system will be handicapped, because they will have to carry larger locomotive weights than the three-phase system.

I do not quite understand how Professor Sawyer received the impression that I referred principally to passenger traffic. Indeed I see almost greater advantages in handling freight service electrically. It is very difficult to show material savings in passenger service, and incidental advantages such as cleaner service, etc., have to be taken into account. In handling freight by electricity it is almost certain that savings can be shown as soon as the traffic is dense enough. It is in this kind of traffic that the three-phase locomotive shows itself at its best. The most powerful and the most robust motor is desired, and these conditions are fulfilled best by the three-phase motor.

Actual practice has established the possibility of using the small air-gaps mentioned. Of course the air-gaps of the New York Central direct-current locomotives are larger, but this is due principally to the fact that the armatures of these motors are on the driving axles and the fields are on the locomotive frame. There is therefore bound to be a relative up-and-down motion between the two. The center of gravity in this construction would seem to be almost too low.

Steam locomotives have their center of gravity much higher and are therefore easier on the tracks. Of course they use side rods and when the first large electric locomotives were designed in America it was considered essential to avoid the use of side rods. In the light of later experiences this would seem to have been unnecessary. In Europe, about 15 years ago, they did not hesitate to use side rods and they still use them to-day. European engineers chose the best point for the center of gravity and they prefer side rods rather than a low center of gravity. Side rods are not as bad as they look. They can be accurately counterbalanced and should not be compared with the strictly reciprocating parts of the steam locomotive, such as piston and coupling rods. Two of the large electrical manufacturing companies are reported to be at work on locomotives with side rods. So this one European idea is evidently beginning to be appreciated. Let us hope that the three-phase system will also soon make its way into American practice.

October Meeting of the Institute

The next regular meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, on Friday, October 8, 1909. The title of the paper to be presented and the name of the author will be announced in the October PROCEEDINGS. The paper itself will also be published in the October PROCEEDINGS.

Twenty-Sixth Annual Convention

REMARKS BY PRESIDENT-ELECT STILLWELL

LEWIS B. STILLWELL: The practice of calling upon the president-elect to appear before the members of the Institute at the convention and let them look at him appears to be of strictly modern origin. I have been wondering, while sitting in my chair and awaiting the summons which I knew was to come, what the first president of the Institute did when he presented himself. I tried to learn something in regard to this procedure, which is a new one to me, by consulting two of the past-presidents, remarking that I thought the practice of requiring the outgoing president to make the address and tell what he has done rather than to ask the man who is coming in to prophesy and tell what he expected to do, was another illustration of the fact that those gentlemen who from time to time have improved the Constitution and By-Laws, had spent a great deal of time thinking the matter over carefully. One of the past-presidents whom I consulted said: " It is all right to go ahead and prophesy," and he added " but be sure not to fix any date." The other one whom I consulted said: " Well, you are not the president until the first of August, and August is a hot month and a long month, and before the autumn comes they will forget whatever you might say."

I notice in the PROCEEDINGS of last August that Mr. Ferguson is reported to have made some off-hand remarks, but they were not printed. I think that is another excellent arrangement, because it is not often that a man can get up here in front of the members of the Institute and say things which are not to be put down in black and white.

The management of the Institute is wisely in the hands of a Board of Directors, and by an excellent provision only four new managers are elected in each year, eight of them holding over. Of the vice-presidents, three hold over. That insures what is very essential in an organization of this kind; namely, continuity of development. That the Institute has advanced since its organization is evidenced by the fact that the Constitution has been amended no less than six times in a period of a little more than 25 years. This indicates that the Institute is awake, and a live and progressive body which has endeavored all this time to keep itself in touch with the great development going on in our country, and particularly with the enormous development of industries which, in one way or another, are related to the electrical arts.

There never was a time, I presume, when any organization of scientific men had greater opportunity to impress themselves individually and collectively upon the industrial development of an art than now, and there never was an engineering society which has had an opportunity equal to that which presents itself to the Institute. The manufactured products of the United States doubled in the 10 years from 1897 to 1907, but the electrical products of the United States doubled in 5 years, from 1902 to 1907. The membership of the Institute, as you know, approximates 6000. The Associates are about 5500.

It is natural and inevitable as the art develops into new fields, and new applications of electricity are made in many directions, that there should become manifest a tendency to form within the large organization of the Institute special groups of men, groups that are particularly interested in one given specialty or another. To my mind one of the problems of the future —and I have no solution now to propose for it—is the problem how we shall modify our organization, our methods, our procedure, as we go along in a manner which will secure in general two results: first, the result of maintaining the high professional standard of our members and dignify our organization in the community in every legitimate way; secondly, recognition of the necessity of providing within the organization for full opportunity for the specialists to discuss their specialties and instruct each other in the development of those particular phases of the art in which they are especially interested.

I think that is one of our large problems which the Board of Directors should take up promptly. I presume they have already given it attention. In fact, I know they have; but it should be followed through, not hastily, because there is a great chance of making a false step in a matter of this kind. It should be taken up logically and carefully and advisedly until we have solved our problem. The problem itself is certainly not less complicated than many of the engineering problems which our members are called upon to deal with. The method of solution, in general, I believe, should be similar to that used in attacking problems in which we are retained to represent the interests of our clients. We must first study the conditions, and make sure that we have all the necessary factors in our mind before a step, which may modify materially what has been so well built up in the past, should be taken.

I wish to refer to the subject of the position of the engineer in the community. That is a subject which I think as members of the Institute, we can very well give attention to. It is a notable fact that the engineers in this country do not hold in general the position in the practical affairs of the business world, of the states, and of the nation, to which their qualifications logically entitle them. So far as their position in matters political is concerned the situation is, of course, their own choice. They are free, as any other citizens, to take a hand in politics or not, as they may determine; but most of us are so busy with our own particular interests that we neglect the opportunity to make ourselves felt in the community. This course may lead to decisions which we all know are unwise, and which may radically affect us as well as other members of the community. For instance, there was a congress held in Washington within the last year on the subject of the improvement of the internal waterways of the country. It was a large congress, and the members were enthusiastic. Their demand was for the improvement of the internal waterways, not only on a moderate scale, limited to the improvement of certain channels, the value of which has been demonstrated; but they went so far as to demand that the federal government should appropriate large sums of money for the construction of a great national system of internal waterway communication. In that whole congress nobody even attempted to prove that if we had these internal waterways, our transportation on the average would be handled at less cost than it would if the same amount of money were put into the railroads. The fundamental economic question underlying the whole subject was absolutely begged at the outset. That is the kind of question I have in mind when I say that the members of our society should take an interest in these public questions by presentation of papers on economic subjects, which will have the effect of enlightening the public. Moreover, they can do a great deal by personal influence and contact with our lawmakers. Many a law has been passed that is harmful in its effect upon the development of one phase or another of our practical business, for the reason that the men who knew the facts were not there at the right time to present them.

Then there is another phase of the many subjects considered by the Institute which I am much interested in, but which I will take only a moment to refer to, and that is the subject of engineering education. We have a very energetic committee on engineering education, which has done some excellent work, which I hope will be continued and extended. I have one thought to offer on that subject—I think that as engineers we recognize very frequently that many of us are more or less handicapped by a certain lack of breadth in our preliminary education. That is not a theoretical idea; it is a practical idea. In these days an engineer may know a subject intimately, but if he cannot appear before a board of directors or a committee, and state what he knows in convincing language, the thing that he wants done is not likely to be put to practical use. No small proportion of the time and effort of the engineers who are in large degree responsible for constructive work in this country consists in presenting the facts in a convincing manner to the people who have the power to decide. Now, in my observation a very large proportion of the younger engineers lack that ability to present their knowledge, and to convince their hearers of the value of their knowledge. In my opinion this deficiency is due very largely to the fact that their education begins to narrow at too early a period. Even in the preparatory school, the last year or two of the preparatory education is often devoted to work along special lines, and the boy who at 15 bids adieu to everything that relates to the humanities or English, or education in general, and begins to specialize becomes an intellectual machine of very narrow range. A lot of them can be hired for $125 a month. Good draughtsmen and fair calculators can be made out of this material, but this is not the way to make engineers.

I do not know whether the Institute as a body can do anything material in correcting this condition, but I think it is a condition that should be corrected. In my opinion during the next 25 years we should place the Institute, and the members of the Institute, on a plane of culture and breadth and recognition in the community, which will be infinitely beyond anything that we have yet attained.

Convention of the Illuminating Engineering Society

The third annual convention of the Illuminating Engineering Society will be held in the Engineers' Building, 33 West 39th Street, New York, on September 27, 28, and 29, 1909.

The following papers will probably be presented:

Ethics of Illuminating Engineering, by E. L. Elliott. *Some Notes on Illuminating Engineering Practice in Europe*, by H. Thurston Owens. *The Importance of Illuminometry in Practical Illuminating Engineering*, by Norman MacBeth. *Efficiency of Lighting Installations*, by A. L. Eustice. *Shades and Reflectors*, by Dr. Louis Bell. *The Design of Reflectors*, by A. J. Sweet. *Diffusing Mediums*, by A. J. Marshall. *Absorption and Diffusion of Various Forms of Glass Surfaces*, by Basset Jones, Jr. *Factory and Mill Lighting*, by L. B. Marks. *The Photometric Laboratory of the United Gas Improvement Co.*, by C. O. Bond. *The new Physical Laboratory of the National Electric Lamp Association*, by E. B. Hyde. *Modern Photometric Practice in an Incandescent Electric Lamp Factory*, by Charles Deshler. *The Problem of Heterochrome Photometry*, by E. S. Millar. *Description of a Demonstration Lighting Installation*, by W. C. Morris. *Discussion of the Efficiency of the Moore Light*, by Messrs. Hyde, Woodwell, Sharp, and Millar.

Electrical Assistant

The United States Civil Service Commission announces an examination on September 29, 1909, at all of the larger cities of the United States to secure eligibles from which to make certification to fill two or more vacancies in the position of electrical assistant in the Signal Service at Large, War Department, at $1,080 per annum, and vacancies requiring similar qualifications as they may occur in any branch of the service, unless it shall be decided in the interests of the service to fill the vacancies by reinstatement, transfer, or promotion.

The examination will consist of the subjects mentioned below, weighted as indicated:

Subjects.	*Weights.*
1. Practical questions in electrical science..	20
2. Practical questions in construction and installation of electrical instruments....	30
3. Training and experience.................	50
Total...........................	100

Applicants should be thoroughly familiar with the practical side of electricity as applied to telegraph, telephone, and cable engineering, and also with the methods of testing and installing electrical instruments used in fire control, such as storage batteries, motor generators, power and telephone switchboards, wireless telegraph apparatus, telegraphs, electric clocks, telephones, etc.

Applicants whose applications show that they have not had sufficient training and experience to entitle them to a rating of at least 70 in that subject will not be admitted to the examination.

Age limit, 20 years or over on the date of the examination.

In accordance with a recent act of Congress an applicant for this examination will be required to be examined in the State or Territory in which he resides and to show in his application that he has been actually domiciled in such State or Territory for at least one year previous to the examination.

This examination is open to all citizens of the United States who comply with the requirements.

This announcement contains all information which is communicated to applicants regarding the scope of the examination, the vacancy or vacancies to be filled, and the qualifications required.

Applicants should at once apply to the United States Civil Service Commission, Washington, D. C., for application Form 1312. No application will be accepted unless properly executed, *including medical certificate*, and filed with the Commission at Washington prior to the hour of closing business on September 18, 1909. In applying for this examination the exact title as given at the head of this announcement should be used in the application.

Sections and Branches

Los Angeles Section

A meeting of the Los Angeles Section was held on May 18 in the University of Southern California. There was an attendance of 60, with Mr. J. E. Macdonald presiding. The subject of the evening, entitled "Tungsten Lamps versus Other Methods of Street Lighting," was presented by Mr. E. L. Sherwood. The executive committee for the year 1909–10 was elected, and is constituted as follows: V. L. Benedict, C. W. Koiner, J. A. Lighthipe, J. E. Macdonald, E. R. Northmore, E. Woodbury.

The final meeting of the Section for the year was held on July 8, 1909, with a total attendance of 98. The report of the election by mail ballot was read. The following officers were elected: J. A. Lighthipe, chairman; J. E. Macdonald, secretary; Ed. Woodbury, assistant secretary.

Philadelphia Section

On June 2 the Philadelphia Section held its annual dinner at the Hotel Poinsettia, Atlantic City, N. J. There were 98 members and guests in attendance. Mr. Ralph W. Pope, secretary of the Institute, was among the guests.

The regular monthly meeting was held on June 14. The following officers were elected for the ensuing year: George A. Hoadley, chairman; H. F. Sanville, secretary and treasurer; Louis J. Costa, assistant secretary; Charles I. Young, Charles Day, and H. A. Hornor, managers.

SAN FRANCISCO SECTION

A meeting of the San Francisco Section was held on July 30, at the Cliff House, San Francisco, under the auspices of the entertainment committee. Mr. Samuel G. McMeen gave an interesting talk on photography in natural colors, illustrating it with lantern slides. No technical subjects were considered, the evening being given over entirely to social relaxation

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President's Address at the 41st Annual Convention of the American Society of Civil Engineers, Bretton Woods, New Hampshire, July 6, 1909.*

BY ONWARD BATES.

It is the duty of the President of the American Society of Civil Engineers to address its members at each Annual Convention, and in this year of our Lord, 1909, and the fifty-seventh of the Society, I have chosen as my subject, " The Status of the Civil Engineers' Profession in the United States of America."

In determining the status of the profession, it is necessary to consider what it is, what are its objects, what it owes to the community, and what is due to it from the public. To ascertain what it is, requires a knowledge of the qualifications necessary for its practice, and what should be expected of its members in their relations with each other and with their employers.

Since this is an address to the members of the American Society of Civil Engineers, it should set forth the relation of the Society to the profession at large, and the Society's obligation to elevate the profession. I realize that I have undertaken a difficult task, and that all I can hope to accomplish is to interest the members of the Society, and to incite them to personal efforts for the improvement of their chosen profession and its establishment upon a more secure professional basis.

Engineers have long desired a concise and sufficient definition of the profession, and failing to obtain one that is satisfactory, have usually fallen back on the old one, attributed to Thomas Tredgold, as it is given in the Charter of the Institution of Civil Engineers, dated June 3d, 1828, which is as follows:

> " The profession of a Civil Engineer, being the art of directing the Great Sources of Power in Nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbors, moles, breakwaters and light-houses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the exchange of cities and towns."

In the eighty-one years since the incorporation of the British Institution, no better definition than the one given by Tredgold had been submitted and perhaps no better definition could have been offered. It was thoroughly comprehensive of the duties of an Engineer in the state of civilization at that period. Since then, in the unparalleled progress of civilization, his duties have been enlarged, diversified, and multiplied, until it seems impossible to state in words what may reasonably be expected of a Civil Engineer at the present time.

Engineers are made, not born. They are preeminently " self-made men," the product of their own works, men producing experience and experience making men. With constant achievement in directing the great sources of power in Nature, the Engineer's vision has expanded and his capacity has increased until at the present time he may justly claim the recognition of the world for what the profession has done for the use and convenience of

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*Reprinted by courtesy of the A. S. C. E., *Transactions*, Vol. LXIV, p. 567 (1909).

Man along all the lines indicated by Tredgold, and in many others not even dreamed of in that day. The profession is young, just in its infancy, and its scope is so comprehensive, and its growth so rapid that it cannot be defined in a few words.

It is plain that the Engineer of today must live up to his privileges, must equal and add to the great achievements of the past, and must continue to progress in the unlimited field of professional work. The Engineer has always been a worker, living for others rather than for himself. His mind has been fixed on professional achievement without regard to personal advancement. He has shown himself to be of the greatest source of power in Nature, and his reward has been mainly in the accomplishment of good for his fellowmen. He is a builder and not a destroyer, adding to the comfort of living for the whole community, and increasing the wealth of the nation. His gain is not based on the loss of others, and the community has not even returned to him the equivalent for what he has given.

Engineers may be justly proud of their calling, and yet it must be recognized that, professionally, they are not well established, either among themselves or in their relations to the public, and that the status of the profession at the present time is not such as they should be satisfied to rest upon.

Any survey of the status of the Civil Engineer is rendered difficult by the diversity of qualifications and requirements. It is frequently stated that the public, which furnishes the means of employment for the Engineer, has little conception of what the work of an Engineer really is, and this is not strange, since Engineers have so much difficulty in defining their calling. This is an age of specialties, and it is a sufficient achievement for an Engineer to become proficient in one line of employment; consequently, an Engineer is engaged to perform any designated work on the basis of his experience and proficiency in executing similar works. As a result, the opinion is formed in the mind of his employer that the field of engineering is restricted to the particular class of work for which he has required an engineer's services. This error is also common in the profession, for the reason that engineers expend their talents in certain lines, and become so engrossed in them that they acquire a limited appreciation of other classes of engineering work.

For the purpose of analyzing the profession and classifying it according to the nature of employment, an analysis has been made from the List of Members of this Society dated February 1909, showing what each of the 2,380 Members has stated to be his occupation. In selecting this limited number, no reflection is intended on the Associate Members, nor on the qualified engineers of this country who are not connected with the Society. It is considered that the Members furnish a sufficient number of representative engineers for a basis of investigation, and that no better list of experienced Civil Engineers can be obtained, since admission to the grade of Member is a certificate of professional attainments and experience, and it is doubtless, also, a fact that, the majority of the engineers of America who are qualified for the grade of Member, are already enrolled as such. The distribution of this list of Members with regard to their occupation, as stated by themselves, is as follows:

U. S. Government Service.

Army Officers	41		
United States Assistant Engineers, etc.	61		
Navy	25		
Reclamation Service	29		
Geological Survey	7		
Coast and Geodetic Survey	4		
Panama Canal (exclusive of Army Officers)	7		
Miscellaneous	10		
	—	184	7.7%

State and Municipal Public Service.			
State Engineers	7		
City Engineers	50		
Water Supply	60		
Sewerage	16		
Streets and Highways	13		
Wharves, Docks and Ferries	8		
Bridges	20		
Miscellaneous	91		
		301	12.7%
Railway Service (including Traction Lines).			
Executive Officers	30		
General Managers	20		
Chief Engineers	99		
Miscellaneous	212		
		361	15.2%
Manufacturing, Contracting, Etc.			
Bridge and Structural Steel Companies	85		
Light and Power Companies	48		
Contracting	156		
Manufacturing and Supplies	129		
		418	17.6%
Consulting Engineers.			
(Civil, Mechanical, Electrical, Sanitary, Hydraulic and Mining)	482		
		482	20.2%
Other Specialties.			
Architects	21		
Professors and Instructors	82		
Editors	6		
Miscellaneous	14		
		123	5.1%
Unclassified	511	511	21.5%
		2,380	100.0%

From this analysis it is not possible to classify Members on the basis of qualifications, but a fair idea of the nature of their employment may be obtained. It is to be observed that 20 per cent of the Members are in the service of the Government, either national or local; 15 per cent are employed on railways; 18 per cent are engaged in manufacturing or contracting operations; 20 per cent are consulting engineers; 5 per cent consist of architects, professors, etc.; and 21 per cent are unclassified. Many of the Members included in this list are also members of the National Societies of Mechanical, Electrical, and Mining Engineers, who, if restricted to one Society, might not elect to be classed among the Civil Engineers. The large number appearing as unclassified consists of those whose names appear in the list of members with their addresses given, but whose occupation is not stated. Many of these are engaged as Consulting Engineers; some were perhaps out of employment when the list was made; some have retired from active work; and others, for reasons of their own, have simply listed their addresses. It is in the nature of the Civil Engineer's occupation to have frequent changes of residence and of employment, and the list only holds good for the particular time at which it was made.

Assuming that engineers in public and railway service, and those engaged in manufacturing, etc., are salaried employees, this general class will be in the majority, the exact proportion being impossible of determination. It is also a safe assumption that, for Associate Members and Juniors, and Civil Engineers who are not members in any grade of the Society, the proportion of salaried engineers throughout the country is much greater than in the grade of Members. It is, therefore, a reasonable inference for the profession at large, that at least three-quarters of those who have employment are engaged for salaries, and that less than one-fourth of them depend on fees for their income.

No attempt is made to classify this list with respect to rank or income. Neither the title of the Engineer, nor the class of employment, indicates the importance of his work. A chief engineer in the railway service may be in charge of 10,000 miles or of 100 miles of line, and in some instances may be vested with executive and administrative power, while in other cases this power is reserved to his employers, and he simply works under instructions. This illustration from the railway service applies to a greater or less degree throughout the list. Outside of the government service, there is no common understanding of the duties, responsibilities, and remuneration attached to any given title for an engineer. All these appear to be fixed by the employers, and to be dependent on their personal appreciation of the man and his work. With the natural desire of employers to get as much as they can, and give in return as little as they must, there is a well-grounded belief that the average pay of the Engineer is less than it should be for the services rendered by him. Under these conditions, engineers are reticent as to their salaries and fees, and, for the purpose of studying their relation to the profession, there is no way of ascertaining what these amount to. It is an unfortunate condition that the rank and value of positions held by engineers are not more definitely fixed, and it may be taken as an indication that the engineer's status is not rightly determined. If this conclusion can be drawn from an examination of the List of Members of the Society, it will apply with more force to a consideration of the much larger number of the engineers of this country who are not included in that list.

Civil Engineers are human, and need food and clothing and shelter in common with all mankind, and yet their subsistence is precarious. As a class, they are scattered over the country, frequently isolated from their fellow-men, and with employment of a temporary nature. They are true pioneers, preparing the way for others, without taking root and growing in the localities where their best work is done, leaving to others the cultivation of the soil which they have planted, and the reaping of profits resulting from their work. They do not generally become identified with local interests, being employed to do special work, and dismissed when that work is completed. Thus the Engineer is a means to an end for other people, who employ his services for a remuneration which is frequently less than their actual value, and who terminate his employment as soon as they feel they can get on without his aid. He is even sometimes classed by his employers as a necessary evil. He is considered an alien in the community, is uncertain regarding permanency of employment, and in consequence is not so capable of making plans for a domestic life as he would be if engaged in some other occupation.

The status of the profession, and the condition of its members, is better than in any former period, and yet neither is what it ought to be and will be, if engineers do their duty. The profession cannot be considered apart from its individual members. That which raises or lowers individual standards will have a corresponding effect on the profession, and any improvement must result from the work of its practitioners. It is incumbent on all engineers to engage in individual and combined efforts for the advancement of the profession, to the end that greater efficiency may be promoted, that the public may be educated into a better knowledge of what it offers, and that rewards which are more commensurate with achievement may be secured.

Let the Engineer, in examining his own condition, apply the methods which he would use if engaged to report on an engineering work, and he will search for the weak points as well as for the elements of strength. If it were a question involving the strength of materials, he would consider the circumstances of growth or the method of manufacture. His own growth may be traced back to the time when, as a youth, he decided that he wished to be a Civil Engineer, and perhaps it will be found that he was of a studious disposition, and interested in cause and effect among things, rather than among people. In his education he sought for facts; his mind was trained to view all things with precision, and to accept that which is susceptible of proof. Then, in his work as an engineer, he was segregated from others operating as a unit, depending on individual effort, and losing much which might have been gained through combined efforts. His training and practice have taught him to regard himself as separated from his fellow-men, with the result that he becomes the tool of those whose aim is to control men and to profit by their knowledge. The end is that he is a servant where he should be a master. Herein lies the weak point in the profession—may I be pardoned for naming it professional narrowness, while I try to point the way to convert weakness into strength. It is necessary for the Engineer to be more of a " mixer " than he has been, and to assume the initiative in many cases in which under similar conditions he has been a follower. He should be a manager, and should give orders to others who can do the work under his direction as well as he himself could do it with the situation reversed. It should not be considered unprofessional for an Engineer to be a capitalist, and, when he takes his proper place as promoter and organizer and shares in the profits of engineering enterprise, he will no longer be taunted with the saying, that " an Engineer is only good to spend other people's money." It is by acquiring individual strength that the Engineer can give strength to the profession.

It is well known that engineers of admitted proficiency often have to work under the direction of men who are unfitted by education and experience to direct engineering work. This is because the Engineer is a workman while the other party belongs to the class of " managers." The Engineer has not reached his proper rank until he can hold the position of manager, as well as that of a designer and supervisor of work. This is no plea for titles, since no title is more honorable than that of Engineer, but it is a plain statement of present conditions. A better position will be secured whenever the Engineer makes it his business to study men as well as materials, and to use them as he does machinery. The advancement must be individual, by fitting one's self for managing duties, assuming those duties, and " making good " in their performance. There is no room in the profession for trades unionism, for by its very nature it lives on competition, and in practice is a race for higher things. Let there be no mistake, however, in construing these higher things. Professional success is not wholly in building public works, or obtaining fame as a designer or director, or in the accumulation of money—all of which are worthy ends—for it includes making the name of the profession honorable, and the promotion of the welfare and happiness of its members; and these separate objects are not inconsistent or conflicting with each other.

The same conditions and circumstances which tend to limit the advancement of the Engineer as an individual have the tendency of limiting the profession as a whole. Segregation and isolation stand in the way of combination for mutual and joint interests. While trades unions, as they are commonly understood to exist, are not to be desired in the profession, the Engineering Societies offer the best means of united effort for its advancement.

The American Society of Civil Engineers is the representative National Society. Its reason for existence is defined in its Constitution, and, to quote exactly, its objects are " the advancement of engineering knowledge and practice and the maintenance of a high professional standard among its members." It is a mutual society, democratic and yet conservative; every right of each member is secured to him by the Constitution, and the acceptance of membership by an engineer is a practical pledge to work for the high objects for which the Society was organized. How these objects may be attained should be the subject of anxious care by all members. The profession may fairly be judged by the character of its National Society, and membership will be an honor, and a certificate of qualifications, in proportion to the reputation of the Society.

University degrees are honorable, but they only certify that the possessor is prepared to enter the practice of his profession, and are not indicative of his accomplishments in it. Membership in local Engineering Societies is creditable, but usually the standards for membership in these societies are not as high as in the National Society, and it is not unusual for men of prominence in the profession to hold membership in both the local and the National Society. The local societies are not rivals of the National Society, there is need for each, and they have a common purpose which should guide them in harmonious coöperation for the good of the profession.

The American Society of Civil Engineers is the exponent of the profession in this country. As an association of leading engineers, it reflects the standing of the profession and presents to the public the means of judging and determining its status. Its diploma is a guaranty of personal worth, and its grades of membership indicate degrees of preparation for practical work. It has a total membership in all grades of more than 5,000, of which about 2,500 are Members, 1,700 Associate Members and 700 Juniors, the remainder consisting of Honorary and Corresponding Members, Associates, and Fellows. To one who has some knowledge of the engineering work accomplished in this country and of what is now in progress, a study of the Society's membership list is conclusive evidence that it represents the profession in America, and that enrolment in that list is an honor to any engineer.

The Society must grow in membership and in prestige as the profession advances, and its diploma becomes more desirable as the institutions of this country become better established. Its standards must be maintained and its representative capacity increased. It is obvious that its ranks should contain as many as possible of the engineers eligible for membership, and its advantages should be so apparent as to secure the enlistment of engineers who sympathize with its objects. To maintain its standards, it is important to guard its gates against the admission of undesirable members as it is to open them wide for the entrance of worthy applicants. In this free country it is not always possible to protect the community by legal restriction of persons. There is nothing except sentiment to forbid an unworthy or incompetent man to call himself a Civil or Consulting Engineer, and to impose himself as such on clients who require the services of engineers but are not competent to select them. A strict regard for professional and personal qualifications will keep such men out of the Society, and, as time goes on and the Society grows in appreciation, these same clients will learn that its certificate of membership guarantees to them the qualifications they wish to secure.

Applications for membership in the Society are wholly voluntary, and the only inducements offered such applicants are the personal benefits to be derived from membership, and the opportunity to participate in its objects. Under the present system of electing members to the different grades by the Board of Direction, every member of any grade, with personal knowledge of the qualifications of an applicant, can render valuable service to the Society by contributing that knowledge to the Board. It is well to emphasize this as of great importance in properly grading such applicants as are found to be eligible for admission to membership. Common justice to all, as well as the best interests of the Society, is secured by correct grading, and the Board is guided in this work by the summary of all the information respecting an applicant, obtainable from all the members of the Society. It is, therefore, most desirable that the fullest information, with respect to qualifications, experience, and personal character, shall be furnished the Board, as it determines whether an applicant is worthy of admission and for what grade he is eligible. With the responsibility for admission to the Society resting on the thirty members of the Board, and the requirement that not less than twenty-five of them shall vote by ballot on the names considered, the applicant's record receives the closest scrutiny, and action is not taken until all the information obtainable is canvassed. Under these conditions, it is difficult for an improper person to obtain admittance to the Society, and the opportunities for errors in grading applicants who are acceptable can be minimized by the coöperation of members who will furnish the data for classifying them.

The standing of the Society among engineers is improving. This is shown by the large increase in the number of applications, and the steadily increasing membership. The Society, by its term of existence, is of mature age, already comprising in its list of members the majority of the experienced engineers of this country, and future accessions will be from the younger members of the profession who will enter as Juniors and Associate Members, the greater part of these being in time transferred to the grade of Member. The profession is popular with young men, and the technical schools are constantly adding to their equipment to meet the demands of students for an engineering education. One Western university has this year nearly nine hundred men enrolled in the four classes of its college of engineering, and as this is only one of a number of similar institutions, it is apparent that the profession at large is growing in numbers with great rapidity. Fortunately, the growth of our new country and the extension of the field of engineering keep pace with this growth of the profession. This increase emphasizes the importance of an established status for the profession, and of the American Society of Civil Engineers, as a means of grading and certifying the qualifications of individuals for practical work.

It is gratifying to note the large number of Juniors in the Society. Young men are needed. They will not long remain young, and after they are trained as Juniors, and become Corporate Members, they will take charge of the Society, and, in turn, of the interests of the young men who follow them in the profession. Young men should be encouraged for their own good to join as Juniors, with the expectation of entering the higher grades whenever qualified, and in the meantime enjoying the benefits of the Society and sharing in its efforts to advance the standing of the profession. The only privileges denied to Juniors are the rights of voting and of holding office. The expression sometimes uttered by a young engineer that he will not join the Society until he can enter as a Member or an Associate Member, is open to the criticism that he denies himself all the benefits of the Society with the exception already stated, and that his utterance discredits the value of membership in it. Aside from the value of professional standing conferred by such membership, there are numerous direct benefits common to all members. As all these have a bearing and influence on the subject of this address, it will not be out of place to make brief mention of some of them. The publications containing papers and discussions on a great variety of engineering subjects, written by the men who do things, are sent to all members in advance and are subsequently published in permanent form with all the discussion to which they give rise. These papers reflect the best current engineering practice, and must pass the ordeal of criticism from all members who wish to discuss them. The Library contains what is perhaps the best collection of engineering books in this country, and is available directly to resident members, and indirectly to non-resident members through searches performed by the Society's staff. The semi-monthly meetings as well as the Annual Meeting and the yearly Convention are enjoyable and profitable to such as are able to attend them. The recognition of each other among members, and the opportunities for acquaintance and friendly intercourse, are incidental benefits which in themselves should be sufficient to create a desire for membership. This should be particularly appreciated by young men who are making places for themselves in the profession. Engineers are men of high character who have a regard for the moral law and a due consideration for each other. They are an unselfish class, and it is not necessary to state that a true Engineer is willing and anxious to advance the interests of his brethren, and particularly of the young man who will take his place and do better work than he has done. One charm of the Engineer's profession lies in its recent progress. Looking backward only so far as some of the older members of the Society can remember, and observing the engineering achievements, executed, in many instances, by men without much education and with few guiding precedents, we can only wonder what the young engineers of to-day may accomplish in their lifetime with the equipment of education, and the great examples furnished by those who have stepped aside to give them the road.

The Society is under obligation to its members to advertise in all proper ways the advantages of employing them. Our National and local government officials, private corporations, and individuals, who require the services of Engineers, should be made aware of the fact that one cannot be a member of the Society in any grade until his personal character, his professional knowledge, and his practical experience have all been investigated by a Board of thirty of the older men in the profession, who are charged with the duty of admitting into the Society only such as are proven to be worthy and competent. The Society cannot become an employment agency, nor can it recommend individuals, or discriminate in any manner among its members, but its membership list should be a reference book for the employing public. Membership in the Society at the present time is a recommendation to employers, and has a money value to those who hold it, and this value will be greatly increased in the near future, as the profession is expanded by the increasing annual additions to it.

Owing to the incoherence of the profession, it has no established code of ethics, and the influence of the Society should be exerted in this direction. The necessity of a code is not so apparent among Civil Engineers as elsewhere, for the reason that it is in the nature of the profession to abhor all that tends to fraud or quackery. Still, a code must exist, even if it is an unwritten one, and the diversity of professional employment is such that nice questions may arise between engineers, or between them and their employers or clients, which may lead them into error. The Society is perhaps not in a position to formulate and recommend such a code, and yet it can do much to establish the right relations between its members. It can, through the influence of its members, exercise a wise restraint on unprofessional tactics. Members acting in their individual capacity may create a sentiment in the profession and among employers for equitable remuneration of the engineer's services. Engineers in administrative positions may stand for fair salaries and professional consideration for those in subordinate positions. Consulting Engineers may educate their clients to a reasonable knowledge of the value of advice, and, by their conduct, may exhibit the distinction between such as are entitled to be termed Consulting Engineers and those who assume the title without the knowledge and experience to qualify them for it. One of the weak spots in the profession is the lack of a standard of capacity. It should be the case that an engineer's rating of competency is established by the opinions of his fellow-engineers, whose duty it is to recognize his merits and class him accordingly. For this reason, engineers should seek to enlarge their acquaintance in the profession, and should desire the honor and responsibility of membership in the Society.

I was unable at the beginning of this address to give a definition of the Engineering Profession, and at its close I feel that I have not defined its status. This address may be subject to the criticism that it relates to the American Society of Civil Engineers, rather than to the status of the Engineer's Profession. The reply to such a criticism is to admit it to be just, and to explain that the subjects are inseparable, and that the status of the profession depends more upon the status of the Society than upon any other factor. I have not attempted any history of the profession, nor any eulogy of the great engineers who have brought it to its present condition, neither have I laid out any definite plan for the future of the profession. My desire will be accomplished if any encouragement has been given to the members of the American Society of Civil Engineers to use all its privileges and associations for the advancement of the objects which warrant its existence.

Personal

Mr. R. L. Lunt has been transferred from the Philadelphia office of the Chicago office of the Electric Storage Battery Company.

Mr. H. B. Emerson, for many years associated with the General Electric Company, had been appointed engineer and master mechanic of the Arlington Mills at Lawrence, Mass.

Mr. R. B. Owens, formerly professor of electrical engineering at McGill University, Montreal, Canada, has joined the engineering staff of the Southern Power Company, Charlotte, N. C.

Mr. B. R. Shover, electrical engineer of the Indiana Steel Company, Gary, Ind., has presented to the Institute a $\frac{1}{4}$ in. section cut from the first steel rail rolled entirely by electric power.

Mr. John W. Henrekson, formerly with the Goodman Manufacturing Company, Chicago, Ill., has accepted a position as electrical engineer with the Hisey-Wolf Machine Company, Cincinnati, Ohio.

Professor V. Karapetoff, of Cornell University, is spending the summer in the power engineering department of the Westinghouse Electric and Manufacturing Company, at East Pittsburgh, Pa.

Mr. H. W. Evans, formerly with the General Electric Company and the Commonwealth Edison Company, is now in the electrical department of the Detroit River Tunnel Company, of Detroit, Mich.

Mr. F. Schabinger, formerly with the Interborough Rapid Transit Company, has accepted a position with the New York, New Haven & Hartford Railroad Company as high-tension operator at the Cos Cob power station.

Mr. J. H. Morecroft, who for the last two years had charge of the electrical laboratories at Pratt Institute, Brooklyn, N. Y., has been appointed instructor in electrical engineering at Columbia University, New York City.

Mr. C. S. Stouffer, has resigned his position in the engineering department of the Westinghouse Electric & Manufacturing Company to accept a position in the engineering department of the National Tube Company, at Kewanee, Ill.

Mr. J. Brodie Smith, manager of the Manchester Traction, Light and Power Company, of Manchester, N. H., was married on July 14 to Charlotte Dodd Stewartson, M.D. Mr. and Mrs. Smith left Manchester after the ceremony for a brief tour.

Mr. J. A. Simpson, formerly of the New York & New Jersey Telephone Company at Newark, N. J., and later with the Taylor Gold Mining Company of Magnolia, Colo., is now employed in the telephone department of the Automatic Electric Company of Chicago.

Dr. Byron Briggs Brackett, who for the last six years has been professor of electrical engineering at the Clarkson School of Technology, Potsdam, N. Y., has been appointed head of the new department of electrical engineering at the South Dakota State College, Brookings, S. D.

Mr. C. E. Frailey has severed his connection with the sales department of the Westinghouse Electric and Manufacturing Company, Minneapolis, to become a member of the firm of Hammond-Dodson Company, of St. Paul. The Company conduct a wholesale land business.

Mr. H. D. Penny has resigned his position as tool and fixture inspector with the Remington Arms Company, Ilion, N. Y., and is now connected with the Toledo Motor Car Company, Toledo, Ohio, as tool and fixture designer. He will make a specialty of the design of manufacturing equipment.

Mr. A. A. Hall recently resigned his position as chief electrician of the Elkins Power Company, Elkins, W. Va., and has accepted the position of electrical inspector with the West Virginia Inspection Bureau. His headquarters are in the Wheeling, W. Va., office.

Mr. L. B. Cramer, formerly with the Portland Railway, Light & Power Company, and who for the last year has been a member of the faculty of Portland Academy, Portland, Oregon, has accepted a position with the Oregon Electric Railway Company, as electrical engineer.

Mr. William J. Berry, until recently an instructor in mathematics at Harvard University, has accepted an appointment as assistant professor of mathematics at the Brooklyn Polytechnic Institute. His address will be 1937 Eighty-third Street, Van Pelt Manor, Brooklyn, N. Y.

Mr. T. H. Endicott, for the last three years superintendent for A. L. Swanson & Company, of Evansville, Ind., severed his connection with that company on May 1 to accept a position in the electrical department of the Fairbanks-Morse Company of Indianapolis, Ind.

Mr. L. H. Haynes will be in Newark, Ohio, this summer in the interests of Mr. H. A. Strauss, of Chicago, consulting engineer for the electrification of the Salt Lake & Ogden Railway, Salt Lake City, Utah. Mr. Haynes will supervise the construction and equipment of the cars for this service.

Professor Morgan Brooks, of the University of Illinois, has engaged passage from San Francisco for Japan. Professor Brooks will make a tour around the world, sailing from San Francisco on the new Japanese turbine steamship Tenyo Maru, on October 12. He expects to return about May 1 next.

Mr. C. W. Hutton, formerly engineer of operation and maintenance for the Great Western Power Company, with headquarters at Sacramento, Cal., has taken a position as superintendent of the operating department for the same company, with headquarters at Room 271 Bacon Building, Oakland, Cal.

Mr. H. T. Carpenter, formerly assistant secretary of the Bristol Company, of Waterbury, Conn., has been appointed general sales manager of the Standard Manufacturing Company, Bridgeport, Conn., manufacturers of wireless apparatus, telephones and electrical supplies. Mr. Carpenter's headquarters will be at Bridgeport.

Mr. E. N. Sweitzer, who has been attending the seamen gunners school, Washington Navy Yard, Washington, D. C., has been ordered as chief electrician to the U. S. S. Yorktown, now at Seattle. During the summer the Yorktown will visit Puget Sound cities, and will also touch at San Francisco, San Pedro, and San Diego.

Mr. Irving C. Harris has succeeded the late A. H. Demrick in charge of the construction and operation of the power transmission system being built by the U. S. Reclamation Service in the Salt River Valley. This includes the 6000-kw. power plant at the Roosevelt dam, a 4000-volt steel tower transmission line, several sub-stations feeding 10,000-volt distribution lines, and a large number of pumping plants supplying water for irrigation in the Salt River Valley. Mr. Harris has been connected with the Edison Electric Company, of Los Angeles, Cal., for the last nine years.

Obituary

Mr. A. A. Knudson, electrical engineer, of New York, died of heart failure on August 13, 1909, at Meadville, Pa., where he had gone early in August to investigate electrolytic conditions in the water mains. Mr. Knudson was born in Southport, Conn. on December 15, 1846. In 1872 he entered the service of the Western Union Telegraph Company, in the construction department. Three years later he became an inspector for the Gold and Stock Telegraph Company. He was the inventor of the Knudson Ticker, which he patented in 1873, and he subsequently invented six other tickers. In 1880 he introduced the Knudson mechanical telephone system. Later he engaged in consultation work. With the development of the electrical science he enlarged the scope of his work, and in recent years made a specialty of electrolysis. He was elected an Associate of the Institute on December 6, 1887, and was transferred to the grade of Member on January 3, 1888. The funeral took place from his home in Brooklyn on August 18. His widow and a brother survive him.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Institute of Architects. Annuary, 1909. Washington, 1909. (Gift.)

American Institute of Architects. Proceedings of the 42d Annual Convention. Washington, 1908. (Gift.)

American Railway Association. Proceedings of the Session of May 19, 1909. New York, 1909. (Gift of American Railway Association.)

Application of the South Shore Traction Company for the Permission and Approval of this Commission for the Construction and Operation of an Extension of its Street Surface Railroad from the Boundary Line Between Nassau and Queens counties to the Queensboro Bridge Plaza, in the Borough of Queens, and for the Exercise of a franchise to operate cars on the Queensboro Bridge. (Case No. 1032.) New York, 1909. (Gift of State of New York Public Service Commission, for the first District, New York.)

Application of the Watertown Light and Power Company and the Watertown Gas Light Company for approval of a consolidation of said companies and for other relief, submitted Feb. 27, 1909. n. p. 1909. (Gift of State of New York Public Service Commission Second District).

——Graphic Wattmeters for alternating or direct current circuits. Single and polyphase wattmeters. Portable meters for direct current circuits.

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——Checking list for perpetual catalogue No. 3001, for the purpose of keeping catalogues up to date.

——April 1909 Discount sheet applying to Perpetual catalogue No. 3001, containing detail and supply apparatus.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa. Folders on.

——Self running sewing machine outfit; has a special constructed motor, and can be attached to any electric light socket.

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——Eight-inch fan motors for alternating and direct current.

——Wattmeters and how to read them, containing illustrations and descriptions on the method and knowledge of reading meters, and checking the monthly consumption of current.

——Circular No. 1079, July, 1909. Westinghouse O. I. W. C. transformers, with cuts and paragraphs on capacities and voltages, cooling, oil, winding and insulation, terminals, and outlet bushings.

——Circular No. 1144, February, 1909. Direct current mill motors, showing detail construction, and controlling devices.

——Circular No. 1163, May, 1909. Type DA small motors for single-phase alternating current circuits, giving illustrations and description of construction, and the numerous applications in home, office, and factory to which these motors can be adopted.

——Circular No. 1164, February, 1909. Type MS mill motors for polyphase alternating current circuits, squirrel cage rotors, constant speed; gives illustrations and descriptions of construction, and cuts of mills where motors are successfully used.

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OF
Electrical Engineers.

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Vol. XXVIII **October, 1909** No. 10

October Meeting A. I. E. E.

The two hundred and thirty-ninth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, on Friday evening, October 8, 1909, at 8 o'clock. Mr. John B. Taylor of the General Electric Company, Schenectady, N. Y., will present a paper entitled: "Telegraph and Telephone Systems as Affected by Alternating-Current Lines." The paper is published in this issue of the PROCEEDINGS. A summary of Mr. Taylor's observations on this interesting subject will be found on page 1332.

November Meeting A. I. E. E.

The November meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West Thirty-ninth St., New York on Friday evening November 12, 1909 at 8 o'clock. Dr. Cary T. Hutchinson, consulting engineer, of New York, will present a paper entitled: "The Electric System of the Great Northern Railway Company at Cascade Tunnel." The paper will be published in the November PROCEEDINGS to be distributed November 1, 1909.

Secretary's Western Tour

Secretary Ralph W. Pope, accompanied by Past-president Chas. F. Scott and Vice-president Paul M. Lincoln attended a joint meeting of the Seattle Section and the Northwest Electric Light and Power Association at the Alaska-Yukon-Pacific Exposition on September 7, 8, and 9. On September 11, Mr. Pope visited the Portland, Oregon, Section, on September 15 and 16 the San Francisco Section, and, one week later, the Los Angeles Section. He will visit the St. Louis Section on October 9, stopping en route from Los Angeles at Stanford University, Visalia, Salt Lake City, and Denver. An extended account of this tour will appear in the November PROCEEDINGS.

October Meeting, A. S. M. E.

The first monthly meeting of The American Society of Mechanical Engineers for 1909-10 will be held in the Engineers' Building, New York, on Tuesday, evening, October 12, at 8 o'clock. A paper will be presented by Professor R. C. Carpenter of Cornell University upon the "High-Pressure Pumping System of New York City." There are two pumping stations comprised in this system which receive power transmitted electrically from several of the electric generating plants of the city. There are five pumping units in each station consisting of five-stage centrifugal pumps driven by induction motors. Each pump has a capacity of 3000 gal. per min. and delivers against a pressure of 300 lb. per sq. in. in the mains.

Joint Convention Northwest Electric Light and Power Association and Seattle Section American Institute of Electrical Engineers, Fine Arts Building, A. Y. P. Exposition, Seattle, September 9, 1909

New Jersey, there being no other person available. Consequently, throughout the sessions I acted in a dual capacity. Thirty-two states were represented, also Alaska, Hawaii, and British Columbia. Two sessions were held daily, and at each session a different chairman presided. The chairmen were: Hon. John Barrett, Director, International Bureau of American Republics; Joseph N. Teal, Chairman, Oregon Conservation Committee, Gifford Pinchot, Chairman of the National Conservation Commission, Washington, D. C.; Hon. B. N. Baker, Maryland, member Joint Committee on Conservation (subsequently elected President of the Congress); Hon. O. J. Salisbury, member Joint Committee on Conservation. Five-minute talks were called for from the various delegates regarding conservation progress in each State. Among those who presented papers or made addresses were: Gifford Pinchot, Dr. W J McGee, and John Barrett, of Washington, D. C., Hon. George C. Pardee, Ex-Governor of California, and Hon. J. W. Ballinger, Secretary of the Interior. About 25 papers were read covering various phases of the subject. Upon invitation of the Committee I had prepared a brief paper upon the subject assigned to me —" The Conservation of Power Through Electricity." When this was reached on the last day of the Congress it appeared to me that nothing definite had been accomplished, and instead of utilizing my twenty minutes for a subject that was well understood, I decided to devote five minutes in an effort to bring about a general movement for the prevention of forest devastation by fire, a phase of conservation upon which I thought all conflicting interests might be united. To further this plan I yielded the remainder of my time to Mr. Pinchot and Professor Condra, Chairman of the Nebraska Conservation Commission, by reason of their interest in the subject. Since the adjournment of the Congress a special agent of the Forestry Bureau has been sent from Washington, D. C., to report upon the causes of forest fires and the best methods of their prevention. During the closing session of the Congress the state delegates were called upon to nominate vice-presidents, one each from their respective states, so that I was given the opportunity of naming the President of the American Institute of Electrical Engineers as a representative of New Jersey, there having been no provision made for the official recognition of engineering associations. Having met during the sessions of the Congress, Chairman John H. Harisberger and Secretary George H. Moore, of the Seattle Section, I conferred with them regarding the program of the joint convention. The technical sessions held on Tuesday were assigned to the American Institute of Electrical Engineers, and were presided over by Mr. Harisberger. Papers were read by visiting Institute members, as follows : " The Trend in Electrical Development ", by Charles F. Scott of Pittsburgh, " Protection of Electrical Equipment ", by Paul M. Lincoln of Pittsburgh, and " The Electric Vehicle as a Correction of Poor Load Factor ", by R. B. Daggett of San Francisco. An address on the " Administration of Institute Affairs " was also given by the Secretary. Greetings from the Schenectady Section were cordially presented by Frank H. Gale. Institute members were invited to participate in the discussions at the subsequent commercial and executive sessions of the Northwest Electric Light & Power Association. The entertainment features provided by the committee embraced two sight-seeing trips about Seattle, a steamboat trip around Lake Washington, a steamboat trip around Bainbridge Island on Puget Sound, passing the U. S. Navy Yard at Bremerton, followed in the evening with a Cafe Chantant at Luna Park pavilion reached by ferry. On September 1, through the courtesy of Chairman Harisberger, I made an automobile trip of 42 miles to the very interesting power plant of the Seattle-Tacoma Power Company at

Snoqualmie Falls, from which current is transmitted to Seattle and Everett. During my stay at Seattle convenient dates were arranged for my visits to other cities, and immediately after the joint convention I went to Portland, Oregon, arriving there Friday evening, September 10. On Saturday morning, accompanied by Secretary Cramer, I called on Chairman O. B. Coldwell, of the Portland Railway, Light and Power Company. Later we were joined by Mr. Scott and his son Eugene, and Mr. Lincoln, also several members of the Portland Section, and taken for a trip over the city railway lines to Council Crest, visiting the Forestry Building on the grounds of the Lewis and Clarke Exposition. In the evening 57 members and guests were present at a dinner in the home of the Commercial Club. Chairman O. B. Coldwell presided and introduced John F. Carroll, editor of the *Telegram*, who in welcoming the guests paid a high tribute to the electrical engineering profession. Responses were made by Messrs. Scott, Lincoln, Gale and the Secretary. Frequent references were made to the vigor and promising usefulness of the " baby Section ", Portland, it being the most recent acquisition, having been authorized by the Board of Directors on May 18, 1909. Mr. Coldwell arranged for a very enjoyable trip on September 12 over the suburban electric railway to Cazadero a distance of about 40 miles, a special car being provided for the purpose, which was occupied by a dozen of the Portland members and their guests. The railway trip proper ended near the present power-house at Cazadero, but the special car was sent over a service track to the dam about a mile further up the Clackamas River. Here connection was made with a scow pushed by a motor boat, which conveyed the party slowly but surely up to the head of slack-water, where borings are being made preparatory to the construction of an additional dam. A bountiful midday dinner in true pioneer style had been provided for the party at the company's house, after which a quick return trip to the city was made. The exchanges of the Home Telephone & Telegraph Company and the Pacific Telephone & Telegraph Company were visited during the afternoon. The next day a visit to Salem was made by the Oregon Electric Railway through the great Willamette Valley, a run of 50 miles. This line is a model of good construction, and operated under steam railway regulations, carrying freight as well as passengers. Its operation is expected to bring about a further development of the agricultural resources of this extensive valley.

Leaving Portland on September 13, I arrived at San Francisco the next evening. A special dinner for local officers and visitors had been arranged for September 15, to which Messrs. Scott, Lincoln, Gale, and the Secretary were invited. Mr. S. G. McMeen acting as toastmaster. On September 16 an informal dinner was given at the Old Poodle Dog restaurant, 99 members and guests attending. Chairman Murphy presided, and Mr. McMeen again officiated as toastmaster. As had already been intimated by Secretary Lisberger, official announcement was made that the Home Telephone Company had offered to the San Francisco Section spacious quarters in its new building at 333 Grant Avenue, which were to be completely furnished through the liberality of Messrs. McMeen and Miller. These kind offers were accepted by the Section with a vote of thanks. Mr. McMeen then introduced the Secretary, who after some general remarks regarding the affairs of the east and the various problems which had confronted the management, spoke of the suggested intermediate grade of membership and proposed technical divisions. He was followed by Messrs. Scott and Lincoln, after which Messrs. Babcock and Black were called upon by the toastmaster to express the views of the San Francisco engineers. On September 17, through the courtesy of Mr. McMeen, engineer of the Home Telephone Company, an opportunity was offered to inspect a complete automatic telephone exchange system in the making. We visited the main building and several branch exchanges, all being of concrete construction, and fire-proof, with underground cables. The most recent developments in automatic devices are embraced in this system, which is rapidly approaching completion.

Upon invitation from Professor H. J. Ryan I visited Stanford University where I addressed the students of the electrical engineering classes at a meeting of the Branch, Friday evening. On Saturday, September 18, I went to Visalia, where I remained over Sunday. Mr. Lewis, of Santa Cruz, found my name on the hotel register, made himself known, and subsequently introduced Mr. Holley of Visalia. Mr. Hays, whom I had expected to meet, had been called to Los Angeles, but I obtained much valuable information regarding the Mt. Whitney Power Company from Vice-President Maddox. Monday and Tuesday were devoted to a side trip to the California Hot Springs.

I arrived at Los Angeles on Wednesday morning, September 22, and was met at the station by Secretary MacDonald and Mr. Northmore. During the forenoon a private electric car was kindly provided for a trip over the extensive system of the Pacific Electric Railway to San Pedro, which is the seaport of Los Angeles, and is now within the city limits, although about 20 miles distant. An important junction point on this line was named "Watts" in honor of an old resident of the same name. Strangely enough it proved to be 7.46 miles from the Los Angeles terminal. A party of about 25 made this t ip which during the day embraced 146 miles, the car making about 40 miles per hour when conditions permitted. In the evening an informal complimentary dinner was given at the Hollenbeck Hotel, at which 68 were present, Chairman Lighthipe presiding. The Secretary upon being introduced spoke of the wonderful public spirit which was everywhere evident in the city, and the superb railway facilities which had been provided to accommodate the growing population. Mr. Gale followed in support of every good thing which could be said of the Pacific coast. Mr. Copeland responded for the city of Los Angeles, while Mr. Monahan sought solace in the rendition of a Chinese solo, which was heartily applauded. On Thursday morning, September 23, a trip was made to Mount Lowe with Messrs. Kean, Smith, Koiner, and others, a very enjoyable luncheon being served at the pretty Alpine Inn on the mountain. The combined cable and electric railway was a very interesting engineering problem. Upon returning from Mount Lowe we joined another party for which a special electric car had been provided for a trip to the Redonda power-house over the Los Angeles-Pacific system, returning via the " short line ", a distance of about 60 miles. This railway follows the coast from Santa Monico to Redonda. Oil is used for fuel at this power-house, which is considered one of the most economical plants in the country. Everything possible was done by Mr. Beck to make this visit enjoyable and instructive to the visitors. On September 24, the famous trip to Santa Catalina Island was made. The panorama of marine life through the glass-bottomed boats was one of the features of the harbor. Mr. and Mrs. Lighthipe were already at the island, and Mr. Gale went over to finish his successful fishing career interrupted by the adjournment of the Frontenac Convention.

On Saturday, September 25, I started for Salt Lake City via the San Pedro route. I was accompanied by Superintendent Dyer of the railway telegraph, who was on his way to Chicago. Mr. Dyer is very proud of his line, which is well maintained, and his operating force, which he considers first-class. He has several men who he believes will soon become Associates of the Institute. Alighting from the train at Salt Lake

City on Sunday, September 26, just as President Taft was boarding the Oregon Short Line train, I was met by a committee from the Utah Society of Engineers, Messrs. Honnold, McNicoll and McGregor representing the electrical engineers, who after putting me up at the University Club gave me a delightful motor ride about the city up to the mouth of Cottonwood Canyon, which was one of the earliest power developments in Utah. In the evening an impromptu dinner brought together such members as could be assembled. My itinerary had allowed but three days at Salt Lake City, to be followed by two at Provo, but the committee changed this plan by arranging for a round trip of one day to Provo. On Monday, September 27, I was again joined by Mr. Scott and his son, and we visited the University of Utah in the afternoon. On Tuesday Messrs. Wilson and McNicoll accompanied us to Provo, where we met Messrs. Anderson, Cheever, and several of our members connected with the Telluride Power Company. The power station, shops and company's quarters are at Olmsted, a charming little spot up the Provo Canyon combining the hum of industry with the beauties of landscape gardening. After a substantial luncheon the party started by motor and carriage for Battle Creek Canyon, about 12 miles distant, where is located a very interesting plant driven by a Pelton water-wheel under 1800 feet head. At this point it had been necessary to build a cable railway to convey material for the pipe line at the time of construction, and this railway is still operated when necessary. The car is primitive, but safe, and the party was hauled up to a height of about 1600 feet over a track 3600 feet in length. The entire trip and return to Salt Lake City was accomplished during the day.

Bingham Canyon was the objective point on Wednesday, and was reached in company with Mr. Honnold by the Denver and Rio Grande train in the morning. We were met by Mr. Timmerman with a team, and were given an opportunity to observe the uses to which electric power is devoted in the mining districts of Utah. The substation is on a considerable elevation well up in the canyon, and the power is distributed for mining railways, air compressing, lighting, etc. The next morning, accompanied by Messrs. Cohn and McNicoll a trip was made to Ogden by the Southern Pacific Railroad. We were met at the station by a Telluride automobile in which we followed a fine road up the Ogden Canyon to the dam from which the water is conveyed in a 72-inch wooden tube along the north side of the canyon to the power-house of the Old Pioneer Electric Company, which is another early Utah installation. All of these plants in Utah are tied together, including also a 200-mile transmission system from Grace, Idaho, so that any serious interruption in the service is effectually guarded against. Upon returning to Salt Lake City I addressed a meeting of about 20 members at the quarters of the Utah Society of Engineers in the Newhouse Building. Among those who took part in the proceedings were Dr. Merrill, President, Secretary McNicoll, Chairman Honnold, Messrs. Wilson, Jones, City Electrician Kelsey, and City Engineer Scidmore. When the project of organizing a Section of the Institute at Salt Lake City was considered some time ago conditions indicated that a local society would be more satisfactory, and the existing organization was the result. On Friday morning, in company with Secretary McNicoll and Mr. Wilson, a trip was made by automobile to the Garfield smelter, which is operated by a 10,000 kw. steam-plant, the power, however, being distributed by electricity. In the afternoon I started for Denver via the Rio Grande route, and the train being two hours late upon reaching Colorado Springs, I decided to remain there over Sunday, arriving in Denver about noon on October 4, which was the opening day of the street railway convention. In calling upon

Professor Goldsborough I learned that he was collaborating with Mr. Dostal in arranging for a luncheon on Thursday which would give me an opportunity to meet the Institute members in Denver and vicinity, as well as several from distant points who might be in attendance at the convention. The response to the invitations was more general than was expected during so busy a week, there being about 40 present. Brief remarks were made by Chairman Goldsborough, O. B. Coldwell of Portland, Charles Hewitt of Philadelphia, H. Clifford Eddy of Washington, J. H. McGraw of New York, J. F. Dostal of Denver, and the Secretary. The Denver Section has been inactive for three years, but electrical interests have become so important that it was believed to be feasible to interest the members in reorganizing. During my trip I had received invitations to visit Ames, Ia., Chicago, Ill., Fort Wayne Ind., St. Louis Mo., and Washington, D. C. Owing to lack of time, and the fact that my return transportation had been purchased via St. Louis and Washington, I could arrange to stop only at the latter two cities.

I left Denver on Friday, October 8, arriving at St. Louis the next evening. I was met at the station by Chairman A. S. Langsdorf, Secretary Lamke, and Mr. Humphrey, who accompanied me to an informal dinner of the Section. There were 25 members present, and the discussion which ensued was devoted largely to the work of the Institute and the plans of the Section for the season. Having learned that Dr. Steinmetz was to speak at Chicago on November 19, the Section voted that he be invited through the Secretary to extend his trip to St. Louis. The next morning Mr. Layman called with his car, and Professor Langsdorf and Mr. Humphrey joined us in a trip through the residential parts of the city including the university and old exposition grounds.

On Monday at noon I started for Washington via the Chesapeake and Ohio route, arriving there on Tuesday afternoon, and attending a regular monthly meeting of the Section which was held at the George Washington University. Chairman Betts stated that it had been the intention to devote the meeting to the subject of " Illumination ", but that they had been disappointed in making a complete program. Major Squier had, however, consented to give an exhibition of his vibratory filament lamp, with which he produced many beautiful effects. His demonstration was followed by a story of the Secretary's Pacific coast trip.

Upon my return to the Institute offices on October 14 I was very much gratified to learn that at the meeting of the Board of Directors on October 8 the President had been requested to express the thanks of the Board to the chairman of the various Sections who had so kindly expressed their appreciation of this official tour. Everything that could be done was done by officers, committees and members to emphasize their good feeling toward the Institute, and the Secretary as its representative. What might appear as a long and wearisome journey of about 8,000 miles, was so interspersed with kindly acts and attentions, that the trip was in every respect a pleasure and a delight. Time and space has permitted but the briefest outline of my experience, and many courtesies may remain unacknowledged, but they have not been intentionally overlooked.

Yours respectfully,
RALPH W. POPE, *Secretary.*

New York November Meeting A. S. M. E.

Two papers will be presented at the meeting of the American Society of Mechanical Engineers to be held on November 9 in the Engineers' Building, New York, at 8:15 p.m. One by Professor Gaetano Lanza and Lawrence S. Smith of The Massachusetts Institute of Technology, on " Reinforced Concrete Beams"; the other by Prof. Walter Rautenstrauch of Columbia University, on " Stresses in Curved Machine Members."

Minutes of October Meeting of the Institute

The two hundred and thirty-ninth meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday, October 8, 1909. President Lewis B. Stillwell called the meeting to order at 8 p.m. Assistant Secretary Hutchinson announced that at the meeting of the Board of Directors held during the afternoon 94 Associates were elected, and six Associates were transferred to the grade of Member. Those present at the Directors' meeting were: President Lewis B. Stillwell, New York; Past-President H. G. Stott, New York; Vice-president Calvert Townley, New Haven, Conn.; Managers W. G. Carlton, New York, S. D. Sprong, New York, A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., H. H. Norris, Ithaca, N. Y., P. H. Thomas, New York, C. W. Stone, Schenectady, N. Y., D. B. Rushmore, Schenectady, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J., and Assistant Secretary F. L. Hutchinson, New York.

The Associates elected at the Directors' meeting were:

ADAMS, ISAAC BENJAMIN, Acting Supt. Colgate Power Div., Pacific Gas & Elec. Co., Colgate, Cal.

ALLEN, WILLIAM DANIEL, 698 Ellicott Square, Buffalo, N. Y.

ALSAKER, ALFRED, Chief Electrical Designer, North Shore Electric Co.; res., 939 W. Division Street, Chicago, Ill.

ARMSTRONG, FRANK HALL, Mechanical Engineer, Penn Iron Mining Co., Vulcan, Mich.

BARKER, JOHN HENRY, Salesman, Diehl Manufacturing Co., 90 Prince St., New York City; res., 466 E. 7th St., Brooklyn, N. Y.

BIESECKER, ARTHUR S., Traveling Electrical Inspector, D. L. & W. R.R.; res., 737 Prescott Ave., Scranton, Pa.

BREWER, J. IRVING, Assistant Engineer, Interborough Rapid Transit Co., 32 Park Place, New York City.

CARLTON, RUFUS HOUDLETTE, Commercial Dept., General Electric Co.; res., 822 Union St., Schenectady, N.Y.

CARR, MAURICE L., Assistant Engineer, Underwriters Laboratories Inc., 217 Ohio St., Chicago, Ill.

CASE, SAMUEL LEE, Electrical Engineer, Stone & Webster Engineering Corporation, Hauserlake, Helena, Montana.

CHAPPELL, WILLIAM CAMPBELL, British Columbia Electric Railway Co., Ltd., res., 1631 Robson Street, Vancouver, B. C.

CLARK, ERNEST LEE, Assistant Engineer, Electrical Dept., N. Y., N. H. & H. R.R. Co., Guilford, Conn.

COCHRAN, ALBERT WILLIAM, Electrical Engineer, Oregonian Publishing Co.; res., 627 5th Street, Portland, Ore.

COOPER, ROBERT GROFF, General Solicitor, General Electric Co., 1003 Majestic Bldg., Detroit, Mich.

DALEMONT, JULIEN EDOUARD, McGill University; res., 128 Stanley St., Montreal, Canada.

DENTON, CHARLES FREDERIC, Porto Rico Power & Light Co., San Juan, P. R.

DORSEY, JOHN WORTHINGTON, Testing Dept., General Electric Co., res., 248 Union Street, Schenectady, N. Y.

ECKWORTH, FRED CANDLER, Draftsman, The Canadian General Electric Co.; res., 312 Boswell Ave., Peterboro, Ontario.

FAUCETT, FRANK FIELDING, Superintendent, The Gardiner Light & Water Co., Gardiner, Montana.

FEBREY, HAROLD H., Electrical Draughtsman, P. T. & T. R.R. Co., 10 Bridge Street, New York City; res., 1153 Mary St., Elizabeth, N. J.

FEIGEL, JOHN RICHARDSON, Superintendent of Construction, Boone County Telephone Co., Boone, Iowa.

FENNO, GEORGE FRANCIS, Advertising Engineer, Geo. H. Gibson Co., 1119 Tribune Bldg., New York City.

FETHERSTONNAUGH, EDWARD PHILLIPS, Professor of Electrical Engineering, University of Manitoba, Winnipeg, Manitoba.

Fligg, Horace Clyde, Draughtsman, Denver City Tramway Co., 816 Majestic Bldg., Denver, Colorado.

Foltz, Thomas Franklin, P. T. & T. R.R. Co., East River Division, New York City.

Geiger, Clayton Farney, Chief Electrician, The Wilmington City Electric Co.; res., 1125 W. 7th St., Wilmington, Del.

Godfrey, John W., Inspector, Substation Dept., N. Y. C. & H. R. R.R. Co., New York City; res., Sherwood Pk., Yonkers, N. Y.

Gude, Richard Emile, Davis, Cal.

Halliday, Clifford, Chief Operator, Great Northern Power Co., Fon du Lac, Minn.

Harmer, Leonard Stanley, In Charge Electric Power, Grandfather Falls Co., Merrill, Wis.

Hawley, Kent Allen, Draftsman, Viele, Blackwell & Buck; res., 2545 Bervenue Ave., Berkeley, Cal.

Hawley, Luther Willis, Electrician, Estey Organ Co., Brattleboro, Vermont.

Heller, George Arthur, Westinghouse Electric & Mfg. Co., Pittsburg; res., Wilkinsburg, Pa.

Herrold, Herschel McKinley, Apprentice Westinghouse Electric & Mfg. Co., Pittsburg; res., 911 South Ave., Wilkinsburg, Pa.

Hoag, Chance Montel, Chief Operator, Division Creek Power Plants, Los Angeles Aqueduct, Independence,Cal.

Hodgson, George Oscar, Student Engineer, General Electric Co.; res., 618 Chapel Street, Schenectady, N. Y.

Hoke, Charles Constantine, Mechanical Engineer, Compania Minera de Penoles, Maupin, Durango, Mexico.

Holland, Ray Kingsbury, Draftsman with G. S.Williams, 205 New Engineering Building, Ann Arbor, Mich.

Hoppin, Glenn H., Electrician on Construction Work, Washington Water Power Co., Reardon, Wash.

Hoy, Walter H., Switchboard Operator, Toronto Electric Light Co.; res., 128 Lennox St., Toronto, Can.

Hutchinson, Miller Reese, Electrical Engineer, 1 Madison Avenue, New York City, res., Deal Beach, N. J.

Iyengar, Srirangam D. S., Superintendent, Bangalore Power & Lighting, Cauvery Power Scheme, Bangalore City, India.

Jensen, Trygve, Assistant in Electrical Engineering, University of Illinois, res., 701 W. Green St., Urbana, Ill.

Johnson, Samuel Andrew, Superintendent, W. T. Weaver Power Co., Asheville, N. C.

Kamerer, Paul Tranger, Instrument and Construction Work, West Penn Rys. Co., Connellsville, Pa.

Kawado, Shuso, Electrical Engineer, Shibaura Engineering Works & Co., Shibaku, Japan.

Kilmore, John Bruce, Engineer, Commercial Department, Scranton Electric Co., Scranton, Pa.

Kohlhausen, Benjamin Franklin, Assistant to Superintendent, Winchester & Washington City Ry. Co., Winchester, Va.

Kribs, Gordon, Electrical Draughtsman, Smith, Kerry & Chace; res., 313 Spadina Ave., Toronto, Ont.

Kun, Emil, Draughtsman, Metropolitan Street Railway Co., res., 51 West 97th Street, New York City.

Laidlaw, Hugh Alexander, Operating & Maintenance Dept., Pacific Gas & Electric Co., San Francisco, Cal.

Landes, Ray Calder, J. G. White & Co., 43 Exchange Place, New York City.

Leilich, Frank Thurman, Special Apprentice, Westinghouse Electric & Mfg. Co.; res., 816 Ross Avenue, Pittsburg, Pa.

Lord, Mount Claud, Electrical Machinist, Electric Dept., United States Navy Yard, Vallejo, California.

McCraig, Stuart James, Lecturer in Dept. of Electrical Engineering, McGill University, Montreal, Canada.

Merrill, Wilbur Lorin, Engineer, Power & Mining Engg. Dept., General Electric Co., Schenectady, N. Y.

MITCHELL, NATHAN JOHNS, President, N. J. Mitchell Co., 7 Pine Strret, New York City.

MOODY, ALEXANDER SKENE, Electrical Engineer, General Electric Co., 609 Colman Building, Seattle, Wash.

MORRELL, HARRY HOUSE, Manager, Tate Accumulator Co. of Canada, Duncan & Pearl Streets, Toronto,Can.

MULOCK, REDFORD HENRY, Testing Dept., Canadian General Electric Co.; res., 336 Rubidge St., Peterboro, Ont.

MUMMA, FRED TYSON, Superintendent, Big Bend Power House, Great Western Power Co., 5120 Grove St., Oakland, Cal.

NOBLE, GEORGE O., Sales Engineer, Westinghouse Electric & Mfg. Co.; res., 527 So. Main Street, Los Angeles, Cal.

NOGGLE, ROY LOUIS, Foreman, Electrical Construction, United States Reclamation Service, Minidoka, Idaho

PARKER, J. ALEXANDER, 1171 10th Street, San Diego, California.

PARRISH, WILLIAM CARDELL, Superintendent, Laramie Light & Power Co., Laramie, Wyoming.

PORTER, GEORGE WILLIAM, Tester, Pacific Tel. & Tel. Co., Seattle, Wash.

PRATT, CHARLES N., Asst. Supt., Electrical Dept., Rochester Ry. & Light Co., Rochester, N. Y.

RASMUSSEN, HANS FREDRICH WILLIAM, Solicitor, Lowell Electric Light Corporation; res., 24 Loring St., Lowell, Mass.

REED, JOEL EARL, Assistant Manager, Chicago Telephone Co., 3334 Michigan Ave., Indiana Harbor, Ind.

RICE, CHAUNCEY BREWSTER, Professor of Electrical Engineering, Yale University, New Haven, Conn.

ROBBINS, ARTHUR HASTINGS, The Electric Light & Power Co. of Abington, No. Abington, Mass.

ROBINSON, WILLIAM, Electrical and Mechanical Engineer, 276 Stuyvesant Ave., Brooklyn, N. Y.

ROOT, HOWARD CLAYTON, Fort Wayne, Electric Works; res., 2817 Barr St., Ft. Wayne, Indiana.

SAURMAN, ATLEE B., Pacific Coast Manager, Standard Underground Cable Co., First National Bank Bldg., San Francisco, Cal.

SCHLINGMAN, PAUL H., Construction Man, General Electric Co., 816 Wainwright Bldg., St. Louis, Mo.

SCHWERIN, BANARD G., Electrical Contractor, 424 Walnut St.; res., 2113 No. 17th St., Philadelphia, Pa.

SHEPARD, EDGAR RAYMOND, Instructor in Physics & Electrical Engineering Oregon Agricultural College, Corvallis, Ore.

SLOCUM, WINTHROP WALLACE, Electrical Draftsman, Carnegie Steel Co., Clairton; res., 5500 Irwin Ave., Pittsburg, Pa.

STONE, DEAN, Electrical Construction Dept., Metropolitan Street Railway Co., New York City.

STONE, HARRY ALBERT, Inspector, Electrical Dept., N. Y. Central & Hudson River R.R., Pelham, N. Y.

SYLWAN, EINAR, District Engineer, Kungl. Trollhatte Kanal & Vattenverk, Trollhattan; res., Skara,Sweden.

TEMPLIN, WALTER WAYNE, Power Apparatus Salesman, Western Electric Co.; res., 326 East 57th Street, Chicago, Ill.

TALBOYS, FRANK POWELL, Manager and Chief Engineer, The Wanganui Electric Tramways, Wanganui, New Zealand.

TANGEMAN, CHARLES LOUIS, Assistant Engineer, Triumph Electric Co.; res., 2706 Eden Ave., Cincinnati, Ohio.

THOMPSON, FRANK FORRESTER, Professor of Electrical Engineering, Rutgers College; res., 91 Bayard St., New Brunswick, N. J.

TUCKER, CHARLES BAILEY, Illuminating Engineer, General Electric Co., Harrison, N. J.; res., Marblehead, Mass.

VAN BYLEVELT, JOANNES SAMUEL, 4 Weimarstr., The Hague, Holland.

VICK, WILLIAM ROBERT, General Supt. The Merchants Mutual Electric Light & Power Co., Santa Barbara, Cal.

von Krogh, Karl Konon, Supt. of Motor, Transformer & Winding Dept., Br. Westinghouse E. & M. Co., Trafford Park, Manchester, England.

Wagley, Oswal Olson, General Supt., Wells Power Co., res., 302 15th Street, Milwaukee, Wis.

Wilkinson, Thomas W., Wire Chief and Supt., Auburn Telephone Co., Auburn, Nebraska.

Wilson, Alexander Massey, Professor of Electrical Engineering, State University of Kentucky, Lexington, Ky.

Woodcock, Lancelot Richard, Switchboard Operator, Construction Camp, Washington Water Power Co., Reardon, Wash.

Wuest, Anthony Roeder, Electrical Engineer, Patent & Litterar Bureau, Felten & Guilleaume-Lahmeyerwerke, A. G., Frankfort-on-Maine, Germany.

The Associates transferred to the grade of Member were:

Rudolph Warner Van Norden, Consulting Engineer, San Francisco, Cal.

George Harvey Jones, Power Engineer, Commonwealth Edison Company, Chicago, Ill.

P. W. Sothman, Chief Engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont.

Charles D. Knight, Electrical Engineer, General Electric Company, Schenectady, N. Y.

Hans Christian Specht, Electrical Engineer, Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa.

David Francis Crawford, General Superintendent, Motive Power, Penn. Lines West of Pittsburgh, Pittsburgh, Pa.

Mr. J. B. Taylor, of the Railway Engineering Department, General Electric Company, Schenectady, presented a paper on "Telegraph and Telephone Systems as Affected by Alternating Current Lines."

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before November 25, 1909.

8868 Vogel, A., Warm Springs, Mont.
8869 Loeb, Albert J., Milwaukee, Wis.
8870 Henningson, H. H., Wilkinsburg, Pa.
8871 Rodwell, G. H., Lyons, N. Y.
8872 Huntington, R. S., New York City.
8873 Phair, H. G., New York City.
8874 Claytor, C. H., Tuolumne, Cal.
8875 Cochran, J. M., Villanova, Pa.
8876 Parker, C. S., North Bend, Wash.
8877 Reinig, E. C., North Bend, Wash.
8878 Lutz, G. A., Kenilworth, N. J.
8879 Porter, L. W., Utica, N. Y.
8880 Ackland, A. E., Wellington, N. Z.
8881 Bragstadt, O. S., Pittsburg, Pa.
8882 Bidwell, M. C., Denver, Colo.
8883 Rote, J. G., Boston, Mass.
8884 Smith, Jay L., St. Joseph, Mo.
8885 Whaley, W. J., Birmingham, Ala.
8886 Ewalt, G. R., Abilene, Kansas.
8887 Baldwin, R. L., Kansas City, Mo.
8888 Frost, Alton, Newark, N. J.
8889 Bowes, W. R., New York City.
8890 Osborne, L. J., Kansas City, Mo.
8891 Terrell, W. P., Prairie View, Texas.
8892 Corrigan, T. E., Bodie, Cal.
8893 Pestel, Arthur, New York City.
8894 Anderson, Mark, Kansas City, Mo.
8895 Harrison, N. F., Winnipeg, Man.
8896 Kilner, J. S., New York City.
8897 Martin, F. D., Fort Scott, Kansas.
8898 Putnam, J. F., Ithaca, N. Y.
8899 Clark, J. C., Cleveland, Ohio.
8900 Baker, C. H., New York City.
8901 Baylie, W. R., Philadelphia, Pa.
8902 Bacon, F. T. H., New York City.
8903 Carey, A. H., Deadwood, S. D.
8904 Carson, J. P., Jr., St. Paul, Minn.
8905 Fishel, A. D., Pittsburg, Pa.
8906 Glasser, M. M., Pittsfield, Mass.
8907 Gorham, J. S., Chicago, Ill.
8908 Hall, W. M., Bayamon, P. R.
8909 Hays, J. L., Baltimore, Md.

8910 Kerr, W. A., Asbestos, Que.
8911 MacNeal, S. R., Philadelphia, Pa.
8912 Noack, H. R., San Francisco, Cal.
8913 Occleston, W. H., Lead City, S. D.
8914 Rhodes, W. K., Lewisburg, Pa.
8915 Sweet, F. L., Eagle Pass, Tex.
8916 Wiggert, J. F., Lead, S. D.
8917 Camp, C. F., New York City.
8918 Colvin, A. D., Troy, N. Y.
8919 Gati, Bela, Budapest, Hungary.
8920 Getz, W. C., New York City.
8921 Hull, C. S., San Francisco, Cal.
8922 Schulte, E. D. N., Troy, N. Y.
8923 Stephens, F. M., Berkeley, Cal.
8924 Williams, W. J., Troy, N. Y.
8925 MacLeod, N. M., Philadelphia, Pa.
8926 Orsettich, R., Birmingham, Eng.
8927 Porter, H. A., Chicago, Ill.
8928 Durand, W. L., New York City.
8929 Lewis, W. W., Pittsfield, Mass.
8930 Nicoll, R. I. D., New York City.
8931 Rose, F. W., St. Paul, Minn.
8932 Sharp, H. L., Buffalo, N. Y.
8933 Maddox, W. C., Champaign, Ill.
8934 Moore, C. R., Lafayette, Ind.
8935 Stanley, Erwin, Pittsfield, Mass.
8936 Turner, C. V., Lawton, W. Va.
8937 Alexander, F., New York City.
8938 Duff, D. S., Madras, India.
8939 Hart, H. L., Mt. Vernon, N. Y.
8940 Ryan, T. F., Ensenada, P. R.
8941 Cousins, V. D., Lafayette, Ind.
8942 Doyle, E. D., Urbana, Ill.
8943 Howe, A. M., Kingston, R. I.
8944 Forbrich, J. J., Brooklyn, N. Y.
8945 Lister, J. G., Vancouver, B. C.
8946 Morrison, W. T., New York City.
8947 Seidel, C. M., Havana, Cuba.
8948 Frueauff, F. W., Denver, Colo.

Total 81.

Applications for Transfer

The following Associates were recommended for transfer by the Board of Examiners October 4, 1909. Any objection to these transfers should be filed at once with the Secretary.

Charles William Ricker, Electrical Engineer, Cleveland Construction Company and the Warren-Bicknell Company, Cleveland, O.

Herman L. Wallau, Electrical Engineer, Cleveland Electric Illuminating Company, Cleveland, O.

Howard L. Beach, Electrical Engineer, Penna. Coal and Coke Company, Cresson, Pa.

The Electric Vehicle as a Corrector of Poor Load-Factor[*]

The advantages of a high load-factor are so manifest as to require no discussion. During the last 10 years great advances have been made in methods of attaining a load-factor of 100 per cent, by the use of household labor-savers that depend upon electric current as their source of power. Perhaps the greatest increase in the day load for the central station has been due to the installation of motors for industrial purposes, although the time of demand for power by these motors during the winter overlaps the time of demand for lighting current, thus increasing somewhat the peak load, yet the average load-factor has been bettered by their installation. From midnight to dawn there is little demand for electric power from the central station, and electric power that could be furnished between the hours of 12:00 at night and 6:00 in the morning, would greatly improve the load-factors of central stations and increase their revenue accordingly. The electric vehicle can be made the means of establishing a load for that part of the twenty-four hours, when it is most desirable for the central station company to furnish it. By the use of the electric vehicle the load is taken off the peak indirectly by filling in that portion of the time when there is small demand for power of any kind.

Many advantages would accrue to the general public as well as to the central station by the general adoption of the electric vehicle. The noise due to horse-drawn trucks and other vehicles would be eliminated; the hardly perceptible hum of the electric motor and transmission apparatus would supersede it. The capacity of streets to accommodate traffic would be doubled by the elimination of the horse, and in some cases trebled—in most cases the horses occupy about one-half the space occupied by the contrivance. The capacity of the streets would be again doubled by the increase in speed, due to the introduction of electric power. This means that the capacity of the streets would be increased by four. The necessity of rough stone-paved streets for the purpose of preventing horses from slipping would be eliminated—all streets could be smoothly paved. Cleanliness would be greatly increased, which would be a great advantage to pedestrians having to cross the streets. Unhealthful and objectionable stables in the congested districts would be eliminated; the electric garage would occupy much less space than the stable and could be in keeping with either the commercial or residence districts. The army of street cleaners would be reduced to a small number.

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[*] Abstract of a paper by R. B. Daggett read at joint convention of Northwest Electric Light and Power Association and the Seattle Section of the American Institute Electrical Engineers, Seattle, September 8, 1909.

The electric motor requires fewer repairs than almost any other type of power apparatus. Any repairs required on the battery could be made without putting the vehicle out of service, as the battery is divided into small sections any one of which could be removed and replaced by another. The repair of the engine on the gasoline driven machine requires the machine to be put out of service during such repairs.

The former indifference of the central stations to the desirability of the electric automobile as a source of revenue is, perhaps, founded on prejudice. Their first impressions of a crude, imperfect machine, should not afterwards hinder its advancement, especially a machine that has so greatly improved with time as has this. What with increased efficiency in running qualities and greater capacity of batteries, it is a far cry from the electric automobile of five years ago to that of to-day. Its energy is supplied after midnight when costly apparatus would otherwise be idle, while the interest on the investment piles up, water power runs to waste, and depreciation continues. Here it is that the electric automobile does service as a grading machine in filling the " valleys " in the load curve. But little extra investment is required to supply the current needed. The demand is steady and it is permanent. The storage battery is probably the best automatic corrector of the load-factor yet devised.

As the most desirab'e customer, the electric vehicle owner should also be the most favored, and as such, entitled to a low rate for current. With a moderate current cost it is no more expensive to keep an electric car than a horse, and central station companies can do more good for themselves by encouraging the use of electric vehicles than in almost any other way.

New Electrical Engineering Department in Iowa State College

The department of physics and electrical engineering at the Iowa State College has been divided into two distinct departments. Professor L. B. Spinney will continue the head of the department of physics, and Professor F. A. Fish has been appointed the head of the electrical engineering department. A new building has just been completed in which the work of the electrical engineering department will be carried.

Electrical Engineering Department at the University of Kansas

The University of Kansas has just established a separate department of electrical engineering. The electrical engineering course was originally established in 1888, but previously to the present year was combined with the department of physics. Professor F. E. Kester, formerly of Ohio State University, has been appointed professor of physics and the head of that department, and Mr. George C. Shaad, formerly an associate professor of electrical engineering at the Massachusetts Institute of Technology, is in charge of the electrical engineering department. This department is occupying temporary quarters in the new engineering building. At present there are 115 students enrolled in the electrical course, 21 of whom are seniors.

Sections and Branches

UNIVERSITY OF ARKANSAS BRANCH

A reorganization of this Branch was effected at a special meeting held on October 5, 1909, at which 22 members were present. Mr. W. B. Stelzner, professor of electrical engineering in the university, was elected chairman. Mr. F. S. White was reelected secretary. Professor W. N. Gladson outlined the work of the Branch for the coming year and spoke of the benefits to be derived by the students from participation in its work. He then conducted some interesting experiments in magnetism and electric welding. The program was concluded with a talk by Mr. Stelzner in which he described the experiences of a new man entering the General Electric Company's works at Schenectady. The Branch will hold meetings on the first and third Thursdays of every month.

ATLANTA SECTION

The Atlanta Section held its opening meeting on October 5, 1909, with an attendance of 25, Mr. A. M. Schoen presiding. A paper on "Low-pressure Turbines", by Mr. J. W. Kirkland, was read by Mr. Bonyun, and discussed by Messrs. Schoen, Bussey, Redding, Bonyun, Gordon, and Professor Wood. The discussion brought out numerous points on efficiency, governing, operation and plant design, in connection with low-pressure turbines.

CLEVELAND SECTION

The Cleveland Section held its first fall meeting on October 1, 1909. The meeting was devoted exclusively to business. The following committees were appointed: Finance, Introduction, Membership, and Papers. The principal part of the evening was taken up by a discussion of the advisability of social meetings and a proposed assessment of the membership to meet the expense of such meetings. Considerable time was also given to the feasibility of inviting into the Section members of various engineering societies for the exchange of meetings. The proposition was discussed at length, but formal action was deferred until the next meeting. Thirty-four members and visitors were present.

UNIVERSITY OF COLORADO BRANCH

There was an unusually large attendance at the opening meeting of the University of Colorado Branch on October 7, 1909, 65 members and visitors being present. After a discussion as to the most suitable evening to hold future meetings, so as to insure the presence of as many members as possible, Mr. A. Camp Streamer gave a talk on the apprenticeship course of the Westinghouse Electric & Manufacturing Company.

FORT WAYNE SECTION

The regular monthly meeting of the Fort Wayne Section was held on Thursday evening, October 14, 1909, and was devoted to the general subject of technical education. In the absence of the author, Mr. P. C. Morganthaler, the first paper of the evening, entitled "Modern Technical Education", was read by Mr. T. W. Behan. This was followed by a paper by Mr. A. L. Hadley on "The Development of the Technical Colleges." Chairman E. A. Wagner then called upon various members present to discuss the subject. Those taking part in the discussion were: Messrs. T. W. Behan, J. V. Hunter, E. A. Wagner, J. H. Hessin, J. J. A. Snook, L. S. Nold, and O. Cooper.

LEHIGH UNIVERSITY BRANCH

This Branch held its first regular monthly meeting on Tuesday evening, October 12, 1909. After the routine business had been transacted, President Broadbend gave a short address of welcome, in which he outlined the work of the Branch for the present year. Professor Esty then gave a talk on the desirability of coöperation with the Institute, and urged the senior class especially to take advantage of the privilege extended by the Institute to students desiring to enroll.

The first paper for the evening was presented by Mr. William Lewis, on " The Potomac Electric Power Plant." Mr. Lewis described the method now in use for the lighting of the City of Washington.

The second paper, on " Westinghouse Apprenticeship Course ", was presented by Mr. W. C. Jackson.

This concluded the program, and the meeting adjourned to Saucon Hall, where refreshments were served.

UNIVERSITY OF NEBRASKA BRANCH

The University of Nebraska Branch held its first meeting for the year 1909–10 on October 5. Professor George H. Morse, the chairman, presided, and led a discussion upon the usefulness of the Branch and pointed out the means to be adopted for doing effective work. Mr. J. C. Hoge was elected secretary, and Mr. C. E. Bennett was elected treasurer.

PHILADELPHIA SECTION

The Philadelphia Section held its opening meeting on October 11, 1909, with Chairman George A. Hoadley in the chair, and a total attendance of 56. Standing committees were appointed as follows: Papers, Membership and Attendance, House and Dinner, Exhibits and Trips, Editing, and Policy of Section. The following special committees were appointed: Educational, Electric Lighting, Electrochemical, Industrial Power, Municipal, and Telegraphy and Telephony.

After the inaugural address by Chairman Hoadley, Mr. Paul Spencer, delegate to the Frontenac Convention, presented his report of the convention. Mr. J. W. Kelly, Jr. presented a paper entitled " Some Glimpses of Municipal Electricity in the West." Mr. J. B. Yaekel, superintendent of the fire alarm telegraph, of Baltimore, opened the discussion, in which Messrs. Hoadley, Devereaux, Spencer, Snook, Hornor Stevens and Whitney took part.

PITTSBURGH SECTION

Fifty-five members of the Pittsburgh Section met in the lecture room of the Carnegie Institute on October 12, 1909, to hear and discuss a paper by Mr. C. B. Auel, on " Arc and Incandescent Welding." The subject is one of much interest to the steel and metallurgical industries of Pittsburgh, and was ably handled by Mr. Auel. Messrs. F. Theodore Nagel, George H. Wood, Frank G. Galbraith, Charles F. Scott, and Julian Kennedy took part in the discussion.

PITTSFIELD SECTION

The Pittsfield Section held a preliminary meeting on October 6, 1909, for the purpose of electing officers for the current year. The result of the election was as follows: Chairman, H. W. Tobey; secretary, L. F. Blume; Executive Committee, H. W. Tobey, L. F. Blume, S. H. Blake. Other committees appointed were, Advisory, Membership, and Entertainment. The first regular meeting of the Section will be held early in November.

ST. LOUIS SECTION

A meeting of the Executive Committee of the St. Louis Section was held on September 27, 1909. Professor A. S. Langsdorf was reelected chairman, and Mr. George W. Lamke was elected secretary. The committee for this year is constituted as follows: Professor A. S. Langsdorf, chairman; Mr. George W. Lamke, secretary; Messrs. R. S. Pattison, C. A. Hobein, Jr., H. Weichsel.

Mr. Ralph W. Pope, secretary of the Institute, was the guest of the Section at its meeting held on October 9, 1909. The meeting took the form of an informal supper in honor of Mr. Pope's visit, and 22 members were present. Mr. Pope spoke on "The Administration of Institute Affairs". His talk was enjoyed by those present, and the hope was expressed that he would be able to make another visit in the near future.

SEATTLE SECTION

The Seattle Section held a joint session in conjunction with the Northwest Electric Light and Power Association during the Alaska-Yukon-Pacific Exposition. The exposition authorities had courteously set aside September 7, 8 and 9 as "Electrical Days", for the benefit of the two organizations. The meeting of September 7 was devoted exclusively to Institute work. Secretary Ralph W. Pope, of New York, who had been delegated to represent the Institute at the session, delivered an address on "The Administration of Institute Affairs." Other Institute officers who were guests of the Section were Past-President Charles F. Scott and Vice-president Paul M. Lincoln, both of Pittsburgh. September 8 and 9 were devoted to the presentation of technical papers. The program was as follows: "Modern Central Telephone Stations", by C. E. Flaeger; "High Efficiency Lamps", a stereoptican lecture by E. W. Sherwood; "Electrical Illumination from the Central Station Basis", by W. M. Hamilton; "The Trend in Electrical Development", by Charles F. Scott; "Protection of Electrical Equipment", by Paul M. Lincoln. A number of social features contributed greatly to the success of the session.

STANFORD UNIVERSITY BRANCH

A meeting of this Branch was held on September 7, 1909. It being the first meeting of the season no papers were read. The general policy of the Branch was outlined, and it was decided to hold the majority of future meetings in the homes of members instead of in the engineering building as has been done in the past.

Another meeting was held on September 22. Mr. Bradley and Mr. Cramer gave informal talks on their experiences while engaged in operating work.

TOLEDO SECTION

A meeting of the Toledo Section was held on October 1, 1909. Mr. M. W. Hansen presided. Mr. George E. Kirk led a discussion on the principles of wave energy as best known in application to the movement of liquids, and as applicable to sound, light, heat and electricity. Mr. Kirk gave special attention to the energy consumed in illumination for the small returns in light, the ordinary incandescent lamp giving perhaps five per cent light rays and 95 per cent heat rays. As a heating device, a purpose for which it was not designed, the lamp is more efficient than fuel stoves, but the cost of electricity for fuel as against coal is a factor worthy of consideration.

Mr. John Gilmartin spoke of the analogy of electric current to water current, illustrating his remarks by sketches and volt and ampere meter measurements in different circuits. Messrs. Cook and Neuber also took part in the discussion.

TORONTO SECTION

The Executive Committee of the Toronto Section held its first fall meeting on October 5, 1909. The result of the vote for nominations for the coming year was determined, and showed the following preference on the part of the local membership: Chairman, H. W. Price; vice-chairman, E. Richards; Executive Committee, A. L. Mudge, R. J. Clarke, H. A. Moore, F. A. Gabey; secretary, W. H. Eisenbeis. The secretary was instructed to notify the local membership of the result of the nominations and to submit the list at the next meeting for the final vote of the membership.

Mr. Mudge, chairman of the papers committee, reported that he had secured a paper from A. J. Soper, chief electrical inspector of Smith, Kerry & Chace, on "Transmission Line Calculations."

WORCESTER POLYTECHNIC INSTITUTE BRANCH

The first meeting this year of the Worcester Polytechnic Institute Branch was held Friday evening, October 8, 1909, in the electrical engineering building. Mr. Ray H. Taber was the presiding officer, and the attendance numbered 350. A brief business meeting was held before the lecture for the evening was announced. Mr. C. E. Putnam was elected to fill the office of Secretary, made vacant by the resignation of Mr. A. A. Nims. This was followed by a report by Mr. Taber of his trip to the Frontenac Convention.

The chairman then introduced Dr. G. R. Olshausen, who delivered an interesting lecture on "The Elements of Glass Blowing", in the course of which he performed several feats in the glass blowing art, explaining the various operations as he proceeded. Various methods of blowing bulbs, thistle tubes and connections were also shown. After the lecture those present adjourned to the general laboratory where refreshments were served.

Junior Electrical Engineer, Geological Survey, November 23-24, 1909

The United States Civil Service Commission announces an examination on November 23-24, 1909, at the chief cities of the United States, to secure eligibles from which to make certification to fill a vacancy in the position of junior electrical engineer in the Technologic Branch of the Geological Survey, at a salary ranging from $960 to $1,200 per annum, and vacancies requiring smiliar qualifications as they may occur, unless it shall be decided in the interests of the service to fill the vacancy by promotion, reinstatement, or transfer.

The examination will consist of the subjects mentioned below, weighted as indicated:

Subjects	*Weights*
1. Physics, mathematics, and properties of materials	10
2. Electricity and magnetism, including electrical testing with special reference to the work to be performed	25
3. Elementary mechanics and mechanical drawing	15
4. Essay of not less than 500 words on one of several subjects relative to electricity or to testing, to be announced at the examination	15
5. Training and experience (rated on application form)	35
Total	100

Applicants should bring for use in the examination a drawing board not less than 18 inches square, a T square, triangles, and other necessary drawing instruments. The duties of the position will include investigations and tests of electrical equipment to determine its safety for use in mines. Applicants must be thoroughly familiar with handling and reading of electrical instruments, methods of connecting and operating electrical motors, generators, transformers, etc., as well as the installation and manipulation of electric circuits and switching apparatus. They must also have a thorough knowledge of mechanical drawing, design, and drafting-room practice, as well as a working knowledge of machine-shop methods and wood and metal working tools.

They must have had an electrical education and training not less than the equivalent of three years in the electrical engineering course of a technical school or college of good standing. Those whose applications do not show that they have had sufficient training and experience to entitle them to a rating of at least 70 per cent in this subject will not be admitted to the examination.

A large part of the tests will be made

with reference to explosive gases and coal dust, and previous knowledge of the properties and characteristics of these, or previous experience in making such tests, will have a bearing upon the rating of the candidate. Age limit, 21 years or over on the date of the examination. Two days will be required for this examination. This examination is open to all citizens of the United States who comply with the requirements.

This announcement contains all information which is communicated to applicants regarding the scope of the examination, the vacancy or vacancies to be filled, and the qualifications required.

Applicants should at once apply to the United States Civil Service Commission, Washington, D. C., for application Form 1312. No application will be accepted unless properly executed, *including the medical certificate*, and filed with the Commission at Washington.

Issued October 21, 1909.

Gift to the Institute Library by the Western Electric Company

A most valuable addition to the Institute library has been received from the Western Electric Company. The gift is a patent specification library, and is the largest and most valuable accession since the gift of the Latimer Clark collection, by Dr. Schuyler Skaats Wheeler.

The library just acquired consists of 461 leather-bound volumes, containing approximately 100,000 specifications. These specifications date back to May 30, 1871, and cover the entire period to December 1908. They embody the telephone, the electric light, electric railways, and the electric motor. From May 30, 1871 up to and including the year 1887 the volumes are complete, and contain all the specifications, certified, issued by the U. S. Patent Department. From July 1887 to December 1, 1908. the volumes contain all the electrical specifications which are not certified.

The cost of the original set was over $4,000 and duplicates of the specifications, if now purchased from the Government, would cost between $4,000 and $4,500. The collection has been accumulated by the Western Electric Company in Chicago.

Personal

CHARLES STRONG has removed from Mexico City to Fulton, Mo., where he is chief engineer of Hospital No. 1.

MR. CECIL HODGSON is now electrical engineer for the Witherspoon-Englar Company, 1250 Monadnock Building, Chicago, Ill.

MR. KENNETH S. JOHNSON has entered the engineering department of the American Telêphone & Telegraph Company, New York City.

MR. C. F. BRAUN has taken the management of the reorganized Standard Engineering Company, power engineers, with offices at 503 Market Street, San Francisco, Cal.

MR. F. P. MCDERMOTT, JR. has taken a position as experimental engineer with the Remy Electric Company, of Anderson, Ind., manufacturers of magneto ignition apparatus.

MR. F. R. STOWE, formerly with the Power, Transit & Light Company, of Bakersfield, Cal., is now engaged in construction work with the Pacific Gas & Electric Company.

MR. L. M. BOISEN has accepted a position with H. M. Byllesby & Company, Chicago, as power engineer. Mr. Boisen was formerly with the Grand Rapids-Muskegon Power Company.

MR. E. C. NEWTON has been appointed superintendent of the Cleveland district of the United Wireless

Telegraph Company, with headquarters at 1428 Schofield Building, Cleveland, O.

Mr. J. C. F. Shafer is stationed at Hadlock, Wash., as resident engineer of the construction of a reinforced concrete factory, and the installation of a plant for the Classen Chemical Company.

Mr. Jay C. Mitchell, who on August 1, 1909 became assistant sales manager of the North Electric Company, has resigned his position to accept a similar one with the Dean Electric Company.

Mr. W. S. Hoskins has resigned his position as shop manager of Kilbourne & Clark Company, of Seattle, Wash., to become sales engineer in the Seattle office of Allis-Chalmers Company.

Mr. H. D. Enderiss has become associated with the Keystone Electrical Instrument Company, of Philadelphia. Mr. Enderiss was formerly the Philadelphia manager of the Chase-Shawmut Company.

Mr. Harry C. Kendall has severed his connection with the Westinghouse Electric & Manufacturing Company to become instructor in railway electrical engineering at the University of Illinois.

Mr. Albert T. Childs has resigned his position as instructor in electrical engineering at the Worcester Polytechnic Institute to accept a similar appointment at the University of Maine, Orono, Me.

Mr. B. Arakawa, who spent one year in the graduate department of Cornell University, went to Germany last August, where he is studying for another year before returning to his home in Japan.

Mr. S. N. Farnsworth, formerly with the Underwriters' Laboratories in Chicago, is now in the transformer division of the Westinghouse Electric & Manufacturing Company at Pittsburgh.

Mr. L. L. Perry, until recently electrical engineer with Dr. F. S. Pearson, has accepted a position in the power and mining engineering department of the General Electric Company at Schenectady.

Mr. A. L. Jones, who for the last five years has been in the testing and engineering departments of the General Electric Company at Schenectady, has been transferred to the company's Denver office.

Mr. G. A. Burnham recently resigned from the engineering department of the General Electric Company, Boston, Mass., to take a similar position with the Condit Electrical Manufacturing Company, Boston.

Mr. L. O. Grondahl, who last year was professor of physics and mathematics at Spokane College, Spokane, Washington, is now instructor in physics at the University of Washington, Seattle, Wash.

Mr. W. H. Evans has resigned as superintendent of the Central California Traction Company, Stockton, Cal., to enter the electrical department of the Southern Pacific Company at Portland, Oregon.

Mr. Herbert Martin, formerly with Maschinenfabrik Oerlikon at Oerlikon near Zürich, has associated himself with Messrs. Brown, Boveri & Company, at Baden, Switzerland, in their electric traction department.

Mr. Edgar I. Wenger, formerly associate in railway engineering, University of Illinois, has resigned his position to accept one as assistant professor of electrical engineering, McGill University, Montreal, Que.

Mr. M. V. Watson, formerly assistant electrical engineer of the Central Colorado Power Company, of Denver, has removed to Prescott, Arizona, to take charge of the Arizona Power Company, as general manager.

Mr. Ralph S. Willis has gone to Muscatine, Iowa, to take an interest in the pearl button manufacturing business with his father, who is one of the oldest manufacturers of sweet water pearl buttons in this country.

Mr. W. H. Rudisill, formerly with the Carolina Power and Light Company as electrical engineer has accepted a similar position with the Southern Traction and Power Company, with headquarters at Burlington, N. C.

Mr. Robert E. Noyes has accepted the position of instructor in the electrical laboratory of Pratt Institute. He was formerly instructor in electrical engineering at Case School of Applied Science, Cleveland, O.

Mr. N. M. Argabrite resigned his position as manager of the Winona Railway & Light Company, Winona, Minn., to become manager of the Public Service Operating Company of Belvidere, Ill., succeeding Mr. C. L. Powell, deceased.

Mr. Irving W. Phillips, of San Francisco, who has been in Mexico for the last year, has given up his position there and is taking a month's vacation at his home in Lynn, Mass., before returning to San Francisco.

Mr. William Henry Reynolds was married on September 27, 1909, to Miss Ida Maude Dool, at Spencerville, Ont. Mr. and Mrs. Reynolds are now residing in New York City at 131 Edgecombe Avenue.

Mr. Daniel S. Smith, who has been with the General Electric Company at Schenectady and in the New York office for the last seven years, recently accepted a position with the Crocker-Wheeler Company at Ampere, N. J.

Mr. James Murray Weed, transformer designing engineer, has left the Westinghouse Electric & Manufacturing Company to enter the transformer engineering department of the General Electric Company at Pittsfield, Mass.

Mr. E. A. FitzGerald, after twenty years of continuous service as chief electrical inspector for the Underwriters' Association of New York State, Syracuse, N. Y., has been appointed by that association consulting engineer for life.

Mr. Samuel S. Holden has been appointed student assistant in physics and electrical engineering in the University of Florida, Gainesville, Fla. Mr. Holden was formerly a student at the Polytechnic Institute of Brooklyn.

Mr. E. A. Hults, who was electrical foreman for the Universal Portland Cement Company, Buffington, Ind., left that company on October 1, and is now in the power and mining engineering department of the General Electric Company, Chicago, Ill.

Mr. C. Remschel has resigned his position as sales engineer in the Seattle office of the Allis-Chalmers Company to go into business as consulting and contracting engineer with offices at 118 Third Avenue, South Seattle, Washington.

Mr. R. O. Gooding has severed his connection with the sales department of the Western Electric Company to accept a position as estimating engineer in the steam and electrical department of the Allis-Chalmers Company, Milwaukee, Wis.

Mr. C. E. Chatfield has severed his connection with the Western Electric

Company at Hawthorne, Ill., and is now with the Terre Haute, Indianapolis and Eastern Traction Company, as substation forman. His address is Greenfield, Ind.

Mr. Arthur G. Bierma, who until recently was connected with the engineering department of the Niagara, Lockport & Ontario Power Company, Buffalo, is now instructor in the experimental engineering laboratory of Sibley College, Cornell University.

Mr. George A. Scott, who for some time was associated with Mr. E. A. Andrews, designing engineer for the Chicago Pneumatic Tool Company, has accepted a position in the department of physics at the University of Maine, Orono, Me.

Mr. S. D. Levings having resigned from the firm of McMeen and Miller, of Chicago, has accepted a position with the Securities Company, 80 Wall Street, New York City, as technical editor of a new publication to be known as *The Telephone Weekly*.

Mr. A. F. van Deinse, who recently completed the installation of a power plant for the El Tiro Copper Company, of Silverbell, Arizona, has accepted a position with the Westinghouse Electric & Manufacturing Company in their El Paso, Texas, office.

Professor Gustav Wittig has resigned from the electrical engineering department of the University of Maine, Orono, Me., to accept the appointment of professor of physics and electrical engineering, University of Alabama, at University, Ala.

Mr. A. D. Miller, who for the last two years has been assistant engineer with the Reno Power, Light & Water Company and the Truckee River General Electric Company, has resigned to accept the position of manager and superintendent of the Reno Traction Company.

Mr. E. B. Bartlett, having resigned his position as salesman and engineer in the Salt Lake City office of the Allis-Chalmers Company, has accepted the position of assistant superintendent of the A. O. Smith Company, automobile parts, Milwaukee, Wis.

Mr. L. L. Smith, formerly engineer with the Beatty Milling, Mining & Reduction Company, of Beatty, Nevada has accepted a position with the Arnold Company, 181 La Salle Street, Chicago, Ill., as designer in the irrigation and hydroelectric department.

Mr. Herbert R. Wilde, who during the last year has been in Brazil and the Argentine Republic in connection with electrical development, has returned to this country and is now in the testing department of the General Electric Company, Schenectady, N. Y.

Mr. Frederic A. De Lay, formerly associate professor of physics and electrical engineering in the Agricultural and Mechanical College of Texas, is now professor of electrical engineering in the State Agricultural College, Fort Collins, Colorado.

Mr. Harry J. Wolf, chief engineer for the Stanley Mines Company, Idaho Springs, Colo., has been appointed consulting engineer for the Western Metals Company, with headquarters at Denver, Colo. Mr. Wolf is secretary of both companies, and a director of the former.

Mr. Emil Leonarz has resigned as electrical engineer for the Mexican Light & Power Company, which position he held for three and a half years, and has accepted a similar position with the firm of Schöndube & Neugebauer, of Mexico City. His address is Apartado No. 756, Mexico, D. F.

Mr. W. M. **Chubb**, assistant electrical engineer in the U. S. Signal Corps, has been transferred from the office of the Chief Signal Officer, Department of California, to the office of the Chief Signal Officer, Philippine Division, U. S. A., where he will be in charge of fire control work in Manilla and Subig Bays.

Mr. Henry R. **Stevens**, former superintendent of electric power, Indiana Steel Company, Gary, Ind., has resigned his position and returned to Seattle, Wash., where he will associate himself with A. S. Downey, consulting engineer, whose specialty is hydro-electric and industrial plants.

Mr. R. C. **Beardsley**, who for the last four years has been chief engineer of the hydraulic department of the Roberts and Abbott Company, of Cleveland, O., has established a consulting engineering business in Cleveland, and will make a specialty of hydraulic and electrical engineering.

Mr. W. G. **Thummel**, of Golconda, Ill., is engaged in the relocation of the Toledo, St. Louis & New Orleans Railroad, which will probably be built next summer. Mr. Thummel has been actively connected with electric and steam railroads since 1892, handling both civil and electrical engineering work.

Mr. H. G. **Welfare** has left the Chicago, Lake Shore and South Bend Railway Company to take a position as assistant engineer on the erection and installation of a new disposal plant for the City of Columbus, Ohio. All of the machinery in the plant will be driven by individual alternating-current motors.

Mr. Humphreys **Milliken**, who for the last two years has been in Portland, Oregon, in connection with the work of W. S. Barstow & Company on the Oregon Electric Railway, recently returned to the company's New York office, and is now in charge of the construction work of the Delaware County Electric Company.

Mr. M. **Berthold**, who for the last four years was connected with the Fairbanks-Morse Electrical Manufacturing Company of Indianapolis, Ind., as engineer and designer of their direct and alternating current machines, has been appointed chief engineer of the Ideal Electric & Manufacturing Company, Mansfield, Ohio.

Mr. Perry O. **Crawford**, who until the date of its completion on August 20 had charge of the design and installation of the Northern California Power Company's new south power house at Manton, Cal., has taken charge of the installation of the Inskip power house for the same company, with headquarters at Paynescreek, Cal.

Mr. G. R. **Hall** has been elected secretary and treasurer of the Di-el-ite Manufacturing Company, Philadelphia, Pa. Mr. Hall was formerly in business at Boulder, Colo., under the name of Hall & Crawford. Prior to that he was with Westinghouse, Church, Kerr & Company, and the Westinghouse Electric & Manufacturing Company.

Mr. W. B. **Stelzner** has severed his connection with the H. L. Doherty Company, of Joplin, Mo., to accept the appointment of adjunct professor in the electrical engineering department of the University of Arkansas, Fayetteville, Ark. Mr. Stelzner has been elected chairman of the Institute Branch at the university.

Mr. A. E. **Tremaine** recently resigned his position with the Eastern Concrete Construction Company, of Boston, Mass., to accept that of electrical engineer for the Oxford Linen Mills, North Brookfield, Mass. Mr. Tremaine will design and supervise the installation of their electrical equipment, which will consist of electric drive on all machines.

Professor Clarence E. Reid, who for the last four years has been assistant professor of electrical engineering at the Case School of Applied Science, has been appointed head of the department of physics and electrical engineering at the Mississippi Agricultural and Mechanical College. Professor Reid was formerly with the Bureau of Standards at Washington.

Mr. George C. Shaad has severed his connection with the Massachusetts Institute of Technology, where he was associate professor of electrical engineering, to accept the appointment of professor of electrical engineering and head of that department at the University of Kansas. The electrical engineering work at this university was formerly in charge of the department of physics.

Mr. H. K. McIntyre recently accepted the position of assistant professor of electrical engineering at North Carolina College of Agriculture and Mechanic Arts, West Raleigh, N. C. Mr. McIntyre was formerly in the engineering department of the New York Telephone Company, and was also for a time connected with the Gray Electric Company and the Gray National Telautograph Company.

Mr. W. E. Wickenden has been appointed assistant professor of electrical engineering at the Massachusetts Institute of Technology, succeeding Professor George C. Shaad. Mr. Wickenden is a graduate of Dennison University. He taught for one year at Rochester, N. Y., after which he took one year's graduate study in physics at the University of Wisconsin. He is now on the electrical engineering staff of the latter university.

Mr. Arthur Bessey Smith, assistant professor of telephone engineering, Purdue University, Lafayette, Ind., has become associated with the Automatic Electric Company of Chicago, in the sales and advertising department, as assistant to Mr. H. D. Critchfield. Prior to his call to Purdue University in September 1905 Professor Smith filled various positions in telephone work, from troubleman to manager, in Iowa, Nebraska and New York.

Obituary

Mr. Frank N. Simpson, of Janesville, Iowa, died on June 10, 1909. Mr. Simpson was born in Janesville, and after graduating from the Iowa State Normal School he went to Denver, Colo., where he entered the employ of Albert Sechrist & Company and engaged in general electrical construction. He remained with this concern for four years. Removing to Minneapolis, Mr. Simpson took a position with the Minneapolis General Electric Company. For the last four of his thirteen years of service with this company he was superintendent of electric power. He became an Associate of the Institute on June 21, 1907.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Railway Association. Committee on Relations Between Railroads Statement of Car Surpluses and Shortages Sept. 29, 1909. Chicago, 1909. (Statistical Bulletin no. 55-B) (Gift.)

Application of the Bondholders' Committee of Bonds issued Under the First Consolidated Mortgage of the Third Avenue Railroad Company, dated May 15, 1900, for Approval of the issue of 16,516,800 of Refunding Mortgage Bonds, 32,000,000 of Adjustment Mortgage 5 per cent Cumulative Bonds and 20,00,0000 of Capital Stock by a New Company Contemplated in the Plan of Reorganization of the

Property of Said Third Avenue Railroad Company. (Case no. 1126). New York, 1909. (Gift of New York State Public Service Commission, First District.)

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Contents.—Chapter I.—Training Apprentices. II.—Methods of Management. III.—Methods of Construction. IV.—Routing of Material. V.—Scaffolds. VI.—The Gilbreth Scaffold-Hod Type. VII.—Gilbreth Scaffold-Packet Type. VIII.—Gilbreth Packet System. IX.—Method of Building Tall Chimneys. X.—Mortar. XI.—Bricks. XII.—Bricklayers' Tools, etc. XIII.—Lines, Plumbs and Poles. XIV.—Motion Study. XV.—Methods of Laying Brick under Special Conditions. XVI.—Finishing Jointing and Pointing. XVII.—Arches and Chimney Breasts. XVIII.—Tearing Down, Cutting Out and Patching Brickwork. XIX.—Bond.

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Contents.—Chapter I.—Direct Current Generators. II.—Direct Current Motors. III.—Synchronous Alternators. IV.—Single-Phase Currents. V.—Transformers. VI.—Polyphase Currents. VII.—Phase Changers, Potential Regulators, etc.

Dynamo Laboratory Manual—Direct Current Studies and Tests vol. I. By W. S. Franklin and W. Esty. New York, Macmillan Co., 1909. (Gift of Publishers.) Price $1.75 n t.

Dynamos and Motors Direct-current and Alternating-current Machines. By W. S. Franklin and W. Esty. New York, Macmillan Co., 1909. (Gift of Publishers.) Price $4.00 net.

Contents.—Part I, Chapter I.—Electric Current. II.—The Dynamo and the Transformer. III.—Direct-current and Alternating-current Measurements. Part II.—Direct-current Generators and Motors. IV.—Operation of a Direct-Current Dynamo as a Generator. V.—Operation of a Direct-Current Dynamo as a Motor. VI.—Power Losses and Efficiencies. VII.—Ratings and Guarantees. Part III.—Elementary Theory of Alternating Currents. VIII.—Harmonic Electromotive Forces and Currents. IX.—Fundamental Problems. X.—Polyphase System. Part IV.—Alternating-Currents Generators and Motors. XI.—Alternator as a Generator. XII.—Synchronous Motor. XIII.—Synchronous Converter XIV.—Simple Theory of the Transformer. XV.—Induction Motor. Part V.—Station Arrangements and Operation. XVII.—Switchboards and Switch board Appliances. XVIII.—Practical Operation of Dynamos.

Effect of Oxygen in Coal. (Bulletin no. 382, U. S. Geological Survey.) By David White. Washington, U. S. Government, 1909. (Gift.)

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Contents.—Chapter I.—Detecting Electricity with a Telephone Receiver. II.—Invisible Lines of Force. III.—Kinds of Currents Produced by Electricity. IV.—The Alternating Current and the Pulsating Current. V.—The Direct Current. VI.—The Undulating Current. VII.—The Oscillating Current. VIII.—Wireless Telegraphy. IX.—Wireless Telephony.

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Public Benefits Derived from Water Power Developments in California. By John Martin. n. p. 1909. (Gift of author.)

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CONTENTS.—Lecture I.—Nature and different forms of radiation. II.—Relation of Bodies to Radiation. III.—Physiological Effects of Radiation. IV.—Chemical and Physical Effects of Radiation. V.—Temperature Radiation. VI.—Luminescense. VII.—Flames as Illuminants VIII.—Arc Lamps and Arc Lighting. IX.—Measurement of Light and Radiation. X.—Light Flux and Distribution. XI.—Light Intensity and Illumination. XII.—Illumination and Illuminating Engineering. XIII.—Physiological Problems of Illuminating Engineering.

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CONTENTS.—Part I.—General Survey. Part II.—Special Apparatus. (*a*) Synchronous Machines. (*b*) Direct-Current Commutating Machines, (*c*) Alternating Current Commutating Machines. (*d*) Synchronous Converters, (*e*) Induction Machines.

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Patents as a Factor in Manufacturing. By E. J. Prindle. New York, 1908. (Gift of author.)

TRADE CATALOGUES

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Sections and Branches—Directory.

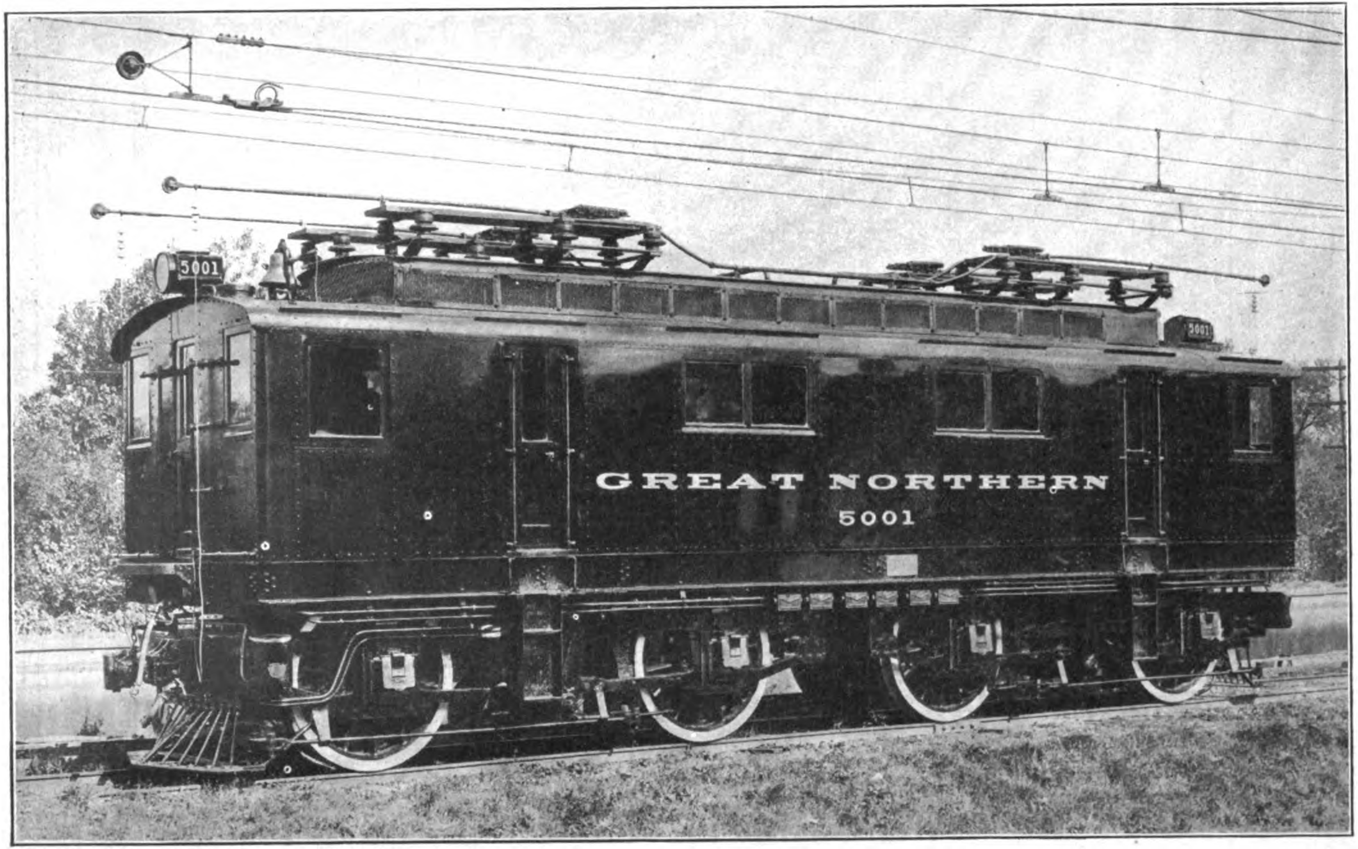
SECTIONS	Organization authorized by Board of Directors	Chairman	Secretary
Atlanta	Jan. 19, '04	W. R. Collier	E. P. Peck, Box 52, Atlanta, Ga.
Baltimore	Dec. 16, '04	J. B. Whitehead	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston	Feb. 13, '03	D. C. Jackson	A. L. Pearson, 93 Federal St., Boston, Mass.
Chicago	1893	W. L. Abbott	J. G. Wray, 203 Washington St., Chicago, Ill.
Cleveland	Sept. 27, '07	H. L. Wallau	F. M. Hibben, 807 The Cuyahoga Bldg., Cleveland, O.
Columbus	Dec. 20, '03	R. J. Feather	H. L. Bachman, 1070 E. Fulton St., Columbus, O.
Fort Wayne	Aug. 14, '08	E. A. Wagner	J. V. Hunter, 506 W. Jefferson St., Ft. Wayne, Ind.
Ithaca	Oct. 15, '02	E. L. Nichols	B. C. Dennison, Cornell Univ., Ithaca, N. Y.
Los Angeles	May 19, '08	J. A. Lighthipe	J. E. MacDonald, 444 P. E. Bldg., Los Angeles, Cal.
Madison	Jan. 8, '09		J. W. Shuster, Univ. of Wisconsin, Madison, Wis.
Mexico	Dec. 13, '07		F. D. Nims, Mex. Lt. & Pr. Co., Mexico, Mex.
Minnesota	Apr. 7, '02		J. C. Vincent, 1313 6th St., S. E., Minneapolis, Minn.
Norfolk	Mar. 13, '08		R. R. Grant, P. O. Box 254, Norfolk, Va.
Philadelphia	Feb. 18, '03	Geo. A. Hoadley	H. F. Sanville, 1708 Sansom St., Phila., Pa.
Pittsburg	Oct. 13, '02	C. B. Auel	E. B. Tuttle, C. D. & P. Tel. Co., Pittsburgh, Pa.
Portland, Ore	May 18, '09	O. B. Coldwell	L. B. Cramer, 720 Corbett Building, Portland, Ore.
Pittsfield	Mar. 25, '04	H. W. Tobey	L. F. Blume.
San Francisco	Dec. 23, '04	C. W. Burkett	S. J. Lisberger, 925 Fanklin St., San Francisco, Cal.
Schenectady	Jan. 26, '03	M. O. Troy	R. H. Carlton, Gen. Elec. Co., Schenectady, N. Y.
Seattle	Jan. 19, '04	J. H. Harisberger	George Holmes Moore, Central Building, Seattle, Wash.
St. Louis	Jan. 14, '03	A. S. Langsdorf	George W. Lamke, Washington University, St. Louis, Mo.
Toledo	June 3, '07	M. W. Hansen	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto	Sept. 30, '03	H. W. Price	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can.
Urbana	Nov. 25, '02	Charles T. Knipp	J. M. Bryant, 506 West Illinois St., Urbana, Ill.
Washington, D. C	Apr. 9, '03	Philander Betts	M. G. Lloyd, Bureau of Standards, Washington, D.C.

Total, 25.

Sections and Branches—Directory.

BRANCHES	Organization authorized by Board of Directors	Chairman	Secretary
Arkansas, Univ. of....	Mar. 25, '04	W. B. Stelzner	F. S. White, 523 Willow St., Fayetteville, Ark.
Armour Institute.....	Feb. 26, '04	Edward Sherwin	J. E. Snow, Armour Inst. Tech., Chicago, Ill.
Case School, Cleveland	Jan 8, '09	K. E. Norton	A. M. Klingman, Case School of App. Science, Cleveland, O.
Cincinnati, Univ. of..	Apr. 10, '08	C. R. Wylie	C. A. Winder, 815 2nd Nat'l Bank Bldg. Cincinnati, O.
Colorado, Univ. of...	Dec. 16, '04	E. A. Robertson	A. P. Sunnergren, 1209 Penn., Boulder, Colo.
Iowa State College ..	Apr. 15, '03	F. A. Fish	Adolph Shane, Iowa State College, Ames, Ia.
Iowa, Univ. of.......	May 18, '09		
Kansas State Agr. Col	Jan. 10, '08	Roy Wilkins	B. F. Eyer, 513 Fremont St., Manhattan, Kansas.
Kansas, Univ. of.....	Mar. 18, '08	Ray Jones	E. J. Thiele, 1042 Tennessee Street, Lawrence, Kan.
Lehigh University.....	Oct. 15, '02	W.W. Broadbend	Howard M. Fry, Lehigh University, Bethlehem, Pa.
Lewis Institute........	Nov. 8, '07	Frank Burch	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06		
Michigan Univ. of...	Mar. 25, '04	E. B. McKinney	Gerald J. Wagner, 454 S. First St., Ann Arbor, Mich.
Missouri, Univ. of..	Jan. 10, '03	H. B. Shaw	H. D. Carpenter, Univ. of Missouri, Columbia, Mo.
Montana State Col ..	May 21, '07	C. C. Kennedy	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of..	Apr. 10, '08	Geo. H. Morse	J. C. Hoge, 2646 Summer St., Lincoln, Nebraska
New Hampshire Col.	Feb. 19, '09	A. M. Buck	
Ohio State Univ.....	Dec. 20, '02	G. A. Arnold	E. C. Williamson, Ohio State Univ., Columbus, O.
Oregon State Agr. Col..	Mar. 24, '08	S. H. Graf	C. Christiansen State Agricultural College, Corvallis, Ore
Penn. State College.	Dec. 20, '02	E. A. Wilcox	H. S Amer, Penn. State College, Pa.
Purdue Univ........	Jan. 26, '03	J. W. Esterline	H. T. Plumb, Purdue Univ., Lafayette, Ind.
Stanford Univ	Dec. 13, '07	C. L. Bradley	C. P. Taylor, Stanford Univ., California.
Syracuse Univ......	Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse Univ., Syracuse, N. Y.
Texas, Univ. of.....	Feb. 14, '08	A. C. Scott	B. E. Kenyon, Univ. of Texas, Austin, Tex.
Wash. State Col. of.	Dec. 13, '07	H. V. Carpenter	M. K. Akers, State Col. of Wash., Pullman, Wash.
Washington Univ...	Feb. 26, '04	C. M. Duncan	H. F. Thomson, 5011 Washington Ave., St. Louis, Mo.
Worcester Poly. Inst..	Mar. 25, '04	Ray H. Taber	C. E. Putnam, Worcester Poly. Inst., Worcester, Mass.

Total 27



General view of Great Northern three-phase locomotive

[Hutchinson]

PROCEEDINGS
OF THE
American Institute
OF
Electrical Engineers.

Published monthly at 33 W. 39th St., New York, under the supervision of
THE EDITING COMMITTEE

GEORGE A. WARDLAW, Editor

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Vol. XXVIII **December, 1909** No. 12

December Meeting on Third Thursday Instead of Second Friday

At the meeting of the Institute Board of Directors held November 12, 1909, a motion was adopted authorizing the postponement of the regular December meeting of the Institute, from the second Friday to the third Thursday in the month. The December meeting will, therefore, be held on Thursday December 16, 1909.

December Meeting A. I. E. E.

The two hundred and forty-first meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York, on Thursday evening December 16, 1909, at 8 o'clock. This meeting will be held under the auspices of the High-Tension Transmission Committee. Mr. Henry L. Doherty will present a paper entitled: " Comments on Development and Operation of Hydroelectric Plants." In addition to the engineering features, this paper closely relates to the conservation of our natural resources, the financing and sale of securities of power projects of all kinds, and the matters of rates, penalties, and insurance of service. It should therefore appeal to those especially interested in these matters as well as to those interested in the purely engineering aspects of hydroelectric enterprises

Technical Committees

The following resolutions were adopted by the Board of Directors of the Institute at the meeting held on November 12, 1909:

Whereas, the progress of the art of electrical engineering and of its allied arts and sciences has reached a point where it is deemed desirable further to systematize the work of the Institute with a view to providing for its members, interested particularly in one or more of the various important subjects which lie within the scope of Institute activity adequate, opportunity for the presentation of papers, oral discussion and written communications relative to their respective specialties; and

Whereas, it is deemed highly important that the TRANSACTIONS of the Institute should contain an adequate record of the progress of the art in each of its various important branches;

Resolved, That in addition to such other special committees as may be appointed by the President from time to time in accordance with Article VII, Section 41, of the Constitution, the President is hereby authorized and instructed to appoint the following special committees; namely:

Railway Committee;
Educational Committee;
High Tension-Transmission Committee;
Industrial Power Committee;
Telegraphy and Telephony Committee;
Electric Lighting Committee;
Electrochemical Committee.

Each of these committees shall comprise nine members or such larger number as may be authorized by the Board of Directors.

It shall be the duty of these special committees to promote and coördinate Institute activity in the respective fields indicated by the names of the several committees.

In respect of papers and discussions, these committees shall report to the Meetings and Papers Committee, and it shall be the duty of the Meetings and Papers Committee to correlate the work of the special committees in such manner as will effectively provide adequate opportunity for discussion of each of the various topics included within the scope of Institute activity and to arrange for the presentation and discussion of such papers as may receive its approval. It shall also be the duty of the Meetings and Papers Committee to provide for the presentation and discussion of all papers relating to subjects within the scope of Institute activity other than those for which initial responsibility is placed upon the special committees above named.

In respect of matters affecting standardization or nomenclature, the several special committees named shall submit to the Standards Committee such recommendations or suggestions as they may deem proper.

In respect of all matters other than those relating to meetings, papers, or standardization, these special committees shall report to the Board of Directors of the Institute.

The chairman of the special committees named shall be ex-officio members of the Meetings and Papers Committee.

Resolved, That the President be and hereby is authorized to increase the Meetings and Papers Committee from five to eleven members, by appointing four members in addition to the chairmen of the seven special committees named above.

Publication of Papers

The following resolution relating to the publication of papers in the Institute PROCEEDINGS and TRANSACTIONS was adopted by the Board of Directors of the Institute at the meeting held on November 12, 1909.

Whereas, the Chairmen of the Meetings and Papers Committee and of the Editing Committee have informally asked for the instructions of the Board of Directors in respect of Sections 33, 34, and 35 of the By-Laws of the Institute;

Resolved, That the Meetings and Papers Committee be and hereby is instructed to select from the PROCEEDINGS for publication in the TRANSACTIONS only such papers of special value as it may deem worthy of permanent record, and in making such selection shall make no distinction between papers presented at the annual convention and regular or special meetings of the Institute and those presented at any meeting of any Institute Section.

The Editing Committee shall be guided by the same rules in respect of discussions and communications.

The Western Electric Gift to the Library

The gift of the Western Electric Company to the Institute library, mentioned at length on page 18 of Section I of the November PROCEEDINGS, was formally acknowledged by the Board of Directors at the regular meeting held on Friday, November 12, 1909. The following resolutions were adopted.

Whereas the Library Committee has reported to this Board that it has received a very valuable gift from the Western Electric Company, consisting of nearly five hundred bound volumes of United States Patent Specifications, cov[illegible] period subsequent to 1871; and

Whereas the Library Committee has already accepted this gift and provided that it should be marked by a special book plate and by an individual label affixed to the outside of each volume both of which shall contain the name of the donor; and

Whereas the Library Committee also reports that it considers this gift the most valuable contribution that it has received since the Wheeler gift; therefore be it

Resolved that the Board of Directors of the American Institute of Electrical Engineers hereby extends to the Western Electric Company its hearty thanks for this valuable gift, and also hereby expresses its appreciation of the generous spirit which has prompted the presentation of this important set of books to our engineering library.

Resolved further, that it is the hope of the Board that this gift may become the nucleus of a complete patent library; and

Resolved, further, that a copy of these resolutions shall be suitably engrossed and sent to the Western Electric Company.

Minutes of November Meeting of the Institute

The two hundred and fortieth meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West Thirty-ninth Street, New York City, on Friday, November 12, 1909. President Stillwell called the meeting to order at 8:25 p.m. Secretary Pope announced that at the meeting of the Board of Directors held during the afternoon 28 Associates were elected, and one Associate was transferred to the grade of Member. Those present at the Directors' meeting were: President Lewis B. Stillwell, New York; Past President H. G. Stott, New York; Vice-presidents Bancroft Gherardi, New York, Paul Spencer, Philadelphia, Calvert Townley, New Haven, Conn.; Managers A. W. Berresford, Milwaukee, Wis., W. G. Carlton, New York, W. S. Murray, New Haven, Conn., H. H. Norris, Ithaca, N. Y., D. B. Rushmore, Schenectady, N. Y., Severn D. Sprong, New York, P. H. Thomas, New York; Treasurer George A. Hamilton, Elizabeth, N. J., Secretary Ralph W. Pope, New York.

The Associates elected at the Directors' meeting were:

ANDERSON, GUSTAVE EMIL, Assistant Installer, Automatic Electric Co., Morgan & Van Buren Sts., Chicago, Ill.

BAILEY, EDGAR LAWRENCE, Electrical Expert, General Electric Co.; res., 119 E. Erie St., Chicago, Ill.

BEAL, HENRY M., Superintendent, Citizen's Light, Heat & Power Co., Montgomery, Ala.

BELL, ROBERT JAMES, Electrical Engineer, Chicago & Southern Traction Co., Chicago; res., 91 154th St., Harvey, Ill.

CAMPBELL, GEORGE, Electrical Superintendent, R. Simpson Department Store; res., 108 Emerson Avenue, Toronto, Ont.

CLINE, WILLIAM HAMLEN, Motor Engineer, General Electric Co.; res., 101 North Common Street, Lynn, Mass.

CONDON, CASIMIR C., Superintendent of Construction, Condon Construction Co., 1531 Unity Building, Chicago, Ill.

COX, JOHN WILLIAM, Chief Engineer, Columbus, & Hocking Coal & Iron Co., Kachelmacher, Ohio.

COXEY, ALBERT CHILDS, Electrician, Pittsburgh Plate Glass Co., Crystal City, Mo.

FRICKEY, ROYAL EVAROL, Electrical Engineer, Northern California Power Co., Redding, California.

GARNIER, EDWARD JACOB, Electric Section Foreman, Indiana Steel Co.; res., 767 Madison St., Gary, Indiana.

HILLEBRAND, PHILLIP HENRY, Division Foreman, Marysville Power Div., Pacific Gas & Elec. Co., Marysville, Cal.

KAROW, EDWARD, JR., Designing Engineer, General Electric Co., Schenectady, N. Y.

KNAPP, MARTIN VALE, Superintendent of Electrical Department, The Union Utilities Co., Morgantown, W. Va.

MARCELL, LAWRENCE POWELL, Electrical Engineer, The National Railways of Mexico, Aguascalientes, Mexico.

MURRAY, WILLIAM WALLACE, Superintendent, Dreamland, Coney Island; res., 92 Montrose Ave., Brooklyn, N. Y.

MYERS, LAURENCE JOSEPH, Consulting Electrical Engineer, 228 W. Borden Ave., Syracuse, N. Y.

NEEL, BLANTON, Engineer, Chattanooga Electric Co.; res., 215½ Vine Street, Chattanooga, Tennessee.

NICHOLS, CHARLES HART, Consulting Engineer, 11 East 24th St.; res., 63 West 127th St., New York City.

NIPPER, AINSWORTH M., Superintendent Electric Light & Power, Board of Public Works, Hannibal, Missouri.

ORR, JOHN, Professor of Engineering, Transvaal University College, Johannesburg, S. A.

RICE, HOMER COKE, Sales Engineer, Westinghouse Electric & Mfg. Co., 209 Central Building, Seattle, Wash.

Rutledge, Henry Benson, Construction Foreman, General Electric Co., Union Trust Building, San Francisco, Cal.

Tillson, Percy E., Assistant, Engineering Dept., Bell Telephone Co. of Pennsylvania, Philadelphia, Pa.

Wadsworth, George Reed, Consulting Engineer, 19 Congress St., Boston; res., Brington Rd., Brookline, Mass.

Wall, Samuel Smith, Superintendent, Town of Pulaski, Light & Water Dept Pulaski, Virginia.

Warren, William Douglas, President & Manager, Warren Electric Co.; res., 117 South Water St., Trinidad, Colorado.

Wyrick, Byron M., Superintendent Construction & Equipt., Postal Telegraph & Cable Co. of Texas, 243 Main St., Dallas, Texas.

The Associate transferred was

Robert Dale McCarter, Consulting Engineer, London, England.

Dr. Cary T. Hutchinson, consulting engineer, of New York City, presented a paper on " The Electric System of the Great Northern Railway Company at Cascade Tunnel." The total attendance at the meeting numbered 529. The paper was discussed by Messrs. L. B. Stillwell, W. S. Murray, E. B. Katte, B. J. Arnold, F. N. Waterman, J. H. Davis, L. R. Pomeroy, W. N. Smith, F. S. Denneen, C. L. de Muralt, Calvert Townley, C. P. Steinmetz, F. J. Sprague, W. I. Slichter, E. F. W. Alexanderson, Cary T. Hutchinson.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before December 24, 1909.

8949 Bullivant, F. J., St. Louis, Mo.
8950 Clarkson, E. P., Cobalt, Ont.
8951 Drake, W. T., Berkeley, Cal.
8952 Millar, S. J., Ipswich, Queensland.
8953 Du Moulin, W. L. Cananea, Mex.
8954 Newman, W. A., Portland, Ore.
8955 Palmer, E. A., Newark, N. J.
8956 Cabot, W. K., Newark, N. J.
8957 Warner, O. C., Ft. Worden, Wash.
8958 Berst, C. B., Pittsburg, Pa.
8959 Chatfield, L. C., Schenectady, N.Y.
8960 Evans, John, Denver, Colo.
8961 Harbolt, P. F., Gary, Indiana.
8962 Sithens, E. J., Philadelphia, Pa.
8963 Adler, G. M., Ketchikan, Alaska.
8964 Butterfield, J. T., Lafayette, Ind.
8965 Chase, G. H., Philadelphia, Pa.
8966 Green, C. W., Boston, Mass.
8967 Dickson, A. A. C., Gaya Dist., India
8968 Hanley, N. F., Pittsfield, Mass.
8969 Hurley, W. P., Pittsburg, Pa.
8970 Lauridsen, L., Portland, Ore.
8971 Mann, N. C., Columbia, Mo.
8972 Price, Bernard, Johannesburg, S.A.
8973 Sanderson, E. W., New York City.
8974 Surface, C. R., Columbia, Mo.
8975 Sweetman, A. H., Chicago, Ill.
8976 Taylor, W. G., Schenectady, N. Y.
8977 Warner, F. L., Schenectady, N. Y.
8978 Garcelon, G. H., Pittsburg, Pa.
8979 Johnson, C. J., Wheeling, W. Va.
8980 Koster, E. J., New York City.
8981 Lloyd, E. M., Newark, N. J.
8982 Marshall, Wm., Ithaca, N. Y.
8983 McCullough, W. W., Jr., Galveston.
8984 Sowles, L. W., Salt Lake City, Utah.
8985 Uyeda, Y., Philadelphia, Pa.
8986 Watson, J. T., Copperhill, Tenn.
8987 Wills, G. M., Goldfield, Nev.
8988 Eby, E. De W., Pittsfield, Mass.
8989 Foster, E. S., So. Bethlehem, Pa.
8990 Howard, O. Z., Annapolis, Md.
8991 Hurd, E., Pasco, Wash.
8992 Page, W. K., Schenectady, N. Y.
8993 Schaefer, J. H., Chicago, Ill.
8994 Sheffer, J. W., Berwick, Pa.
8995 Wooten, O. B., College Station, Tex.
8996 Beers, H. S., Schenectady, N. Y.
8997 Crego, S. M., Schenectady, N. Y.
8998 Harding, V. A., Kansas City, Mo.
8999 Murphy, R. G., Schenectady, N.Y.
9000 Read, G. C., Cobalt, Ont.
9001 Rogers, J. W., Camden, N. J.
9002 Rossman, A. M., Schenectady, N.Y.
9003 Sigwalt, E. J., Chicago, Ill.

9004 Wynne, V. C., Albany, N. Y.
9005 Abbott, A. H., Pittsfield, Mass.
9006 Hellmuth, W. F., Harleigh, Pa.
9007 Clark, R. P., Schenectady, N. Y.
9008 Eardley, M. V., Schenectady, N. Y.
9009 Fletcher, G. H., Preston, England.
9010 Millar E, G. B., Columbia Mo.
9011 Lawrence, H. E., Rochester, N. Y.
9012 Barnett, E. L., Fort Bragg, Cal.
9013 Farnsworth, L. D., New York City.
9014 Hamilton, H. L., Philadelphia, Pa.
9015 Jacobi, W. O., Chicago, Ill.
9016 Kawara, M., Schenectady, N. Y.
9017 Streamer, A. C., Wilkinsburg, Pa.
9018 Hawkins, H. C., Mexico City, Mex.
9019 Linter, J., St. Petersburg, Russia.
9020 Sibley, H. S., Birmingham, Ala.
9021 Thut, Paul, Bern, Switzerland.
9022 Urban, F., Milwaukee, Wis.
9023 Warnimont, R. K., Chicago, Ill.
9024 Stanton, R. M., Cohocton, N. Y.
9025 Keith, D. F., Provo, Utah.
9026 Symington, S, Christchurch, N. Z.
9027 Vincent, J. J., Christchurch, N. Z.
9028 Dawson, H. L., Chicago, Ill.
9029 Dustin, F. G., Minneapolis, Minn.
9030 Hoole, F. G., Chicago, Ill.
9031 Jacobucci, J. H., Rawlins, Wyo.
9032 Powell, H. C., Hamilton, Ont.
9033 Pratt, F. C., Urbana, Ill.
9034 Ward, Evans, Port Chester, N. Y.
9035 Ward, W. L., Port Chester, N. Y.
9036 Weirich, P. J., Monroe, Wis.
9037 Le Fever, O. L., Portland, Ore.
9038 Watt, H. H., Tarrytown, N. Y.
Total, 90.

Applications for Transfer

The following Associates were recommended for transfer by the Board of Examiners at a meeting held on November 11, 1909. Any objection to these transfers should be filed at once with the Secretary.

William Robinson, electrical and mechanical engineer, Brooklyn, N. Y.

Ezra Frederick Scattergood, consulting electrical engineer and chief electrical engineer, City of Los Angeles, Cal.

Paul Winsor, chief engineer, motive power, Boston Elevated Railway System, Boston, Mass.

Adolphus Mansfield Dudley, designing engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Annual Meeting of the American Society of Mechanical Engineers

The thirtieth annual meeting of the A. S. M. E. will be held in the Engineers' Building, 33 West 39th Street, New York, December 7 to 10, 1909.

The entire social entertainment will be in charge of the members resident in and about New York, under the immediate direction of a local committee appointed by them, of which Mr. William D. Hoxie, is chairman. For Wednesday afternoon, December 8, a general excursion is planned. There will also be opportunities for smaller parties to visit places of interest. In the evening there will be a lecture for members and guests upon the subject of agricultural machinery.

The professional papers assigned to the meeting are as follows: *Tests on a Venturi Meter for Boiler Feed*, Chas. M. Allen; *The Pitot Tube as a Steam Meter*, Geo. F. Gebhardt; *Efficiency Test of Steam Nozzles*, F. H. Sibley and T. S. Kemble; *An Electric Gas Meter*, C. C. Thomas; *Tan Bark as a Boiler Fuel*, David M. Myers; *Cooling Towers for Steam and Gas Power Plants*, J. R. Bibbins; *Some Studies in Rolling Mill Engines*, W. P. Caine; *An Experience with Leaky Vertical Fire-Tube Boilers and the Best Form of Longitudinal Joint for Boilers*, F. W. Dean; *Testing Suction Gas Producers with a Koerting Ejector*, C. M. Garland, and A. P. Kratz; *Bituminous Gas Producer*, J. R. Bibbins; *The Bucyrus Locomotive Pile Driver*, Walter Ferris; *Line-Shaft Efficiency, Mechanical and Economic*, Henry Hess; *Pump Valves and Valve Areas and A Report on Cast-Iron Test Bars*, A. F. Nagle.

In addition to the above papers there will be several valuable reports submitted by committees of the Gas Power Section.

American Institute of Chemical Engineers

The annual meeting of the American Institute of Chemical Engineers will be held at the Hotel Walton, Philadelphia, December 8–10, 1909. In addition to business sessions, social functions, and visits to various points of interest, the following papers will be presented:

Natural Draft Gas Producers and Gas Furnaces, by Ernest Schmatolla. *The Commercial Extraction of Grease and Oils*, by Wm. M. Booth. *Address of the retiring president.* Address: *The Chemical Industries of America*, by Chas. E. Munroe. *Multiple Effect Distillation*, by F. J. Wood. *The Advantages of the Multiple Effect Distillation of Glycerine and other Products*, by A. C. Langmuir. *Reclaiming of Waste India Rubber*, by S. P. Sharples. *Materials for Textile Chemical Machines*, by Frederick Dannerth. *A Method for Smelting Iron Ore in the Electric Furnace*, by Edward R. Taylor. *Chemical Composition of Illinois Coal*, by A. Bement. *Heat Efficiency of Smokeless Combustion, and Heat Absorbing Capacity of Boilers*, by A. Bement.

Society of Naval Architects and Marine Engineers

The seventeenth general meeting of the Society of Naval Architects and Marine Engineers was held in the Engineers' Building, November 18 and 19, 1909. The following papers were presented:

Evolution of Screw Propulsion in the United States, by Charles H. Cramp. *The Effect of Parallel Middle Body Upon Resistance*, by D. W. Taylor, U. S. N. *The Influence of the Position of the Midship Section on the Resistance of Some Types of Vessels*, by H. C. Sadler. *Some Ship-shaped Stream Forms*, by Wm. McEntee, U. S. N. *Applications of Electricity to the Propuslion of Naval Vessels*, by W. L. R. Emmet. *The Producer-Gas Boat Marenging*, by H. L. Aldrich. *Building and Equipping Non-Magnetic Auxiliary Yacht Carnegie with Producer Gas Propelling Equipment*, by Wallace Downey. *The Design of Submarines*, by Marley F. Hay. *The Foreign Trade Merchant Marine of the United States. Can it be Revived?* by George W. Dickie. *Material Handling Arrangements for Vessels on the Great Lakes*, by Alexander E. Brown. *Structural Rules for Ships*, by James Donald. *Rivets in Tension*, by Robert Curr. *The Strength of Watertight Bulkheads*, by William Hovgaard. *Cruising Motor Boats*, by E. T. Keyser.

Boston Meeting A. A. A. S.

The American Association for the Advancement of Science will hold its sixty-first meeting in Boston, from December 27, 1909, to January 1, 1910. Several of the affiliated scientific societies will hold their sessions in Boston at the same time. A preliminary program may be obtained from Leland O. Howard, secretary, Smithsonian Institution, Washington, D. C.

Training Teachers of Industrial Arts at Columbia.

The demand for competent teachers of industrial arts has led Teachers College, Columbia University, to plan a series of night courses, by which young men who have a first rate technical ability in the Mechanic Arts can prepare themselves for the profession of teaching. These courses are being offered at night in the School of Industrial Arts of Teachers College, covering mathematics, drafting, design, woodworking, machine-shopwork, industrial chemistry, industrial history, methods of teaching industrial arts. A three years' course of night work will enable an expert mechanic, otherwise qualified, to gain a diploma as teacher of industrial arts.

The opening meeting of The Illuminating Engineering Society (London) took place on November 18, 1909. Silvanus P. Thompson, the first president of the society, presented an inaugural address.

Engineering Responsibility.*

Few fields of study are more fruitful of results and lead to more genuine progress than a study of the causes of failures. Such studies may be unpleasant and disagreeable, they may at times be even disheartening, but the man who would make substantial advances must heed the lessons which his failures teach. It is true that valuable information can be obtained likewise from a study of materials which have given successful service. And, ofttimes, when attacking a new problem, a comparison of the properties and characteristics of those parts of a structure which have behaved well in service with the characteristics and properties of those which have failed in the same service, is a most satisfactory method of approach. And yet, it is doubtful whether the study of failures does not give the more positive information. Faraday, who spent his life in experiment, used to say that he learned more from his failures than he did from his successes. And it is not difficult to see why this should be so. When an experiment or a construction has proved successful we are naturally most interested in the result, and do not usually spend time and thought and study over the details which have led to our success. On the other hand, if our experiment or construction is a failure, the cause of the failure is immediately sought for, every detail is questioned, and it is this study of the details which broadens our knowledge. Quite in line with Faraday's statement is the rather more homely phrase, with which you all are doubtless familiar, and which we remember to have seen somewhere in engineering literature, that " the scrap heap is the place to learn."

Closely connected with the query as to the cause of failures is the ofttimes more important question, who is responsible for the failure? If the matter in hand is an experiment which we are making for our own information, the question of responsibility is small and is practically swallowed up in the cognate question of the cause of the failure. But if, on the other hand, the failure involves the loss of human life or the destruction of valuable property, the question of responsibility may be very grave. And if we may trust our observation, the location of the responsibility for failure is not always an easy matter. I remember to have heard a former editor of *Harper's Magazine* say in a public lecture: " The general habit of humanity is to throw the teaching of the sermon over into the adjoining pew and keep practically none of it for ourselves." Much the same way is it with responsibility for failures. With each and all of us it is usually the other fellow and not ourselves that should be held accountable. In view of the situation it has occurred to us that it might not be amiss on this occasion to spend a little time over the cause of, and responsibility for, failures in engineering constructions.

In our studies of failed and broken parts in connection with our work at Altoona for now some years, we have been gradually led to ascribe failures to one or more of the four following causes, viz., to bad material, bad workmanship, bad or faulty design or to unfair treatment.

Let us spend a few moments with each of these possible causes of failure. First, bad material. This does not cover those cases where the wrong kind of material was used or material not adapted to the work. If cast iron is used when steel should have been employed, if the steel is brittle when the service requires tough, tenacious metal, this is no fault of the material. Failures due to the employment of material unfitted to the service come under another category. Nor can the material be blamed if the size of the part which fails is too small. This cause of failure also comes under another category. But material is bad, and may justly be charged with being the cause of failure when it is different from what those who put it in service had a reasonable right to expect it to be. A rail with a bad pipe in the head, an axle made from a badly segregated bloom, a piece of concrete in which the materials are improperly mixed or contain not enough or inferior cement are all examples of bad material, and if failure comes the failure may justly be charged to the material.

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* Presidential Address delivered before the American Society for Testing Materials, on June 29, by Charles B. Dudley.

The query may naturally arise here, ought not the factor of safety employed to be sufficient to care for the uncertainties of material, so that the total output of a works could be made use of in service? We once knew an officer of a steel works who wanted to have one grade of steel used for all purposes, and who, when told that car axles made of that grade of steel would not be strong enough to hold up the load, replied, " use more of it; that is, make the axles bigger." Undoubtedly there is a necessary relation between the factor of safety and some of the uncertainties of manufacture, but it can hardly be allowed that the producer should then throw upon the consumer all the uncertainties of material. We cannot help thinking that our definition of bad material is sound, viz.: Material is bad when it is different from what those who put it in service had a reasonable right to expect it to be. If the material is bought on specifications, it is reasonable that it should be what the specifications call for. And even if it is bought on indefinite, verbal or written order, such material should be supplied as the buyer had a reasonable right to expect would be furnished.

But why is there ever any difficulty between the producer and consumer about material? The price is agreed upon when the order is taken and the quality of the material is either specified or understood. Why, then, does not the producer always furnish good material?

Our experience on this point has brought us face to face with several explanations of the difficulty we are considering. First and perhaps most important is the price. It is constantly urged that the consumer will not pay the price requisite to secure the materials desired. No information is usually given as to how far the wished-for price, requisite to secure such good materials as the producer would like to furnish, covers a desire for large profits, and consequently consumers have always been a little slow in attaching much weight to this excuse. Prices are largely determined by competition, and in the absence of something more than a verbal statement from the producer that better materials would be furnished at a higher price, he would be a bold purchasing agent that would pay the higher rate. On the other hand it is undoubted that competition is the antagonist of quality, and where materials are brought without reasonable specifications rigidly enforced there is unquestionably much weight in the contention of the producer.

Another reason or excuse for poor materials is that processes and methods of manufacture do not always and every time yield the desired first quality product. Strive as the manufacturer may, the works always turn out some material that is inferior. Taking one illustration from the steel industry, it is well known that every heat is not equally as good as every other, and that a part of each ingot is inferior to the remainder of it. Of course, all of this inferior part that cannot be sold must necessarily remain as scrap, to be worked over again, with the result that the manufacturing cost of the marketable product is necessarily increased. Hence the tendency to crowd the limits and force upon the purchaser all the merchantable material possible, even though some of it may be inferior. It is fair to say that there is a good deal of human nature in this phase of our subject, and if only those of us who are without sin are entitled to cast stones we greatly fear very few stones will be thrown.

Another and most pernicious excuse for furnishing bad materials is the attempt so common everywhere on the part of producers to usurp the legitimate functions of both the consumer and his expert. This manifests itself in the statement, so commonly made by those furnishing material, that it is good enough for the purpose, thus arrogating to themselves the right to decide not only how the material shall be made, but also what kind of material the consumer and his engineer shall use. Pernicious though this custom may be, a good deal may be said in palliation of it. The practice is the outgrowth of an historical situation. In the earlier days, when the consumption of materials was only a fraction of what it is at present, the producer of any material was supposed to know not only how to manufacture it, but also its characteristics and how it would behave in service, and consequently consumers who in those days had scarcely begun to study for themselves the behavior of materials in service, naturally turned to the manufacturers for counsel as to what materials to use. This practice is still in vogue, and it is to be confessed that, where it is employed, no legitimate criticism of the producer can be made if he urges that the material is good enough for the purpose. On the other hand, as time progressed, and large consumers began to study for themselves the behavior of materials in service, as they began to employ their own experts, as testing machines and laboratories began to increase, as, indeed, a society for testing materials came into existence and knowledge of the properties and characteristics of materials began to widen, it is evident that the situation has changed and that where materials are bought on definite specification, the voice of the producer as to quality is no longer potent, and that the old excuse for inferior materials, that they are good enough for the purpose, is no longer entitled to consideration or weight. We are entirely ready to allow that the study of materials, during both the process of manufacture and their behavior while they are in service, is a legitimate field of activity for both producer and consumer, and, as is well known, we have persistently urged with all the force that we were capable of, that while specifications are being made there should be the heartiest coöperation on the part of both; but the specification having been decided on and the contract placed in accordance therewith, there really seems to be very little room left for excuse for furnishing materials that do not meet the requirements, because they are, in the judgment of the producer, good enough for the purpose.

We intentionally refrain from discussion that excuse for poor materials which has its foundation in an overweening desire to make money, since it is so clear that the producer who does not give a reasonable equivalent for the money that he receives must necessarily have a short business life. We are quite ready to acknowledge that no hard and fast line can be drawn between quality and continued business success, and yet we fancy few will deny that the man who sells inferior, worthless or adulterated materials which do not give satisfaction at the price of good ones, will have serious difficulty in securing a second or third order for the same kind of goods, In our own experience, and, let it be stated modestly, partly as the result of our own tests, a number of firms who formerly did quite large business with railroads have either gone out of existence or have been forced to seek business in other fields than those which they formerly cultivated with such unfair profit to themselves.

Coming now to the second cause for failure in structures, bad workmanship. That bad workmanship is a far too frequent cause of failures is common experience. The tendency to slight the job is almost universal. A rivet or a bolt is left out, with consequent increased strain on those which are actually put in, a forging does not fill out the pattern, or the metal is burned, or a weld is defective. We knew a case once where the construction on a passenger coach involved the safety of human life, and where the drawings required that there should be two nuts on a bolt and the end of the bolt riveted over. After the cars had been in service a few weeks and some minor repairs were being made, it was discovered that the bolts originally used in a number of the cars were too short, that the second nut only grasped one or two threads, and that the remaining space in the nut had been filled with putty, so manipulated and stained as to give the appearance of the riveted end which the drawings called for. We knew of another case where two ends of a gas pipe in a small house were joined with putty, instead of with the well-known sleeve or thimble. Fortunately the odor of the gas from a slight leak in the defective joint led to its discovery and repair before anything serious happened. There is little doubt that the experience of each of you will furnish quantites of cases of bad workmanship, and we have known engineers who did not hesitate to declare that bad workmanship was the principal cause of failures in service.

Those of you who have frequently been brought into contact with the results of bad workmanship have no doubt, like myself, often wondered why work was so badly done. Not infrequently in contemplating a failure in which bad workmanship played an important part, we have said to ourselves, " there was absolutely no excuse." And yet since workmanship is so important an element in our theme, it may not be amiss to go a little deeper into the matter. Every one will recognize lack of skill, general inefficiency and simple plain laziness as important elements in bad workmanship. But since these are individual characteristics it probably would not yield any valuable results to discuss them. It is true the apprentice system or lack of apprentice system which is characteristic of many trades might, perhaps, justly be blamed for lack of skill, but it would lead us too far to consider this point.

No doubt many will claim that inferior or insufficient compensation is the most fruitful cause of poor quality of work at the hands of those who, in our industrial system, play the part of hewers of wood and drawers of water. But if we are right, the experience of the last few years has not seemed to confirm this view. If this was the real explanation it would seem to necessarily follow that voluntary increase in wages would bring an increase in efficiency. On the other hand, if we may trust the indications that we have been able to gather, the increase in efficiency following voluntary increases in wages has been most disappointing. We must apparently look further for the real reason for poor workmanship.

In our judgment, the method of compensation for work performed has a direct and most important influence on the quality of the service rendered. We refer especially to the piecework system in those places where it is applicable, and to the payment of all interested in proportion to the amount of successful output, which is so common in the steel industry. Both these methods of compensation stimulate output at the expense of quality, and it is not at all strange, perhaps, that after constructions have found their way into service, we should not infrequently find evidences of the haste, the slurring over, and the inferior workmanship which these methods have necessarily done so much to stimulate. We are not at all prepared to suggest any substitute for them, and we are, and have been for many years, an advocate of them from the standpoint of successful management; but it is folly for us to close our eyes to the fact that the piecework and other successful output methods of compensation of workingmen are antagonistic to quality of work, and that, despite all our efforts to the contrary, they may justly be held responsible for some of our engineering failures.

One more phase of the workman problem. Close observers of the modern workman have noticed for some years a growing tendency on his part to manifest less and less interest in his work. Esprit de corps, pride in his work, and a genuine feeling of loyalty and devotion to the establishment of which he forms a part are gradually becoming less and less. The allegiance of the workman, under the influence of the ferment and agitation which now pervades our whole industrial system, is gradually passing over, in a measure at least, to the labor organization. Instead of coöperation there is ofttimes antagonism. Instead of zeal and earnestness on the part of the workman to do his best there is study how to make the organization stronger and secure greater benefits for himself. The effect of this transfer of allegiance on the quality of the work performed needs no elucidation.

It is not at all our purpose to discuss the labor problem, and this statement of the situation is cited only because it throws a valuable side light on the question we are considering. We may, however, be permitted a single statement, viz.: We are firmly convinced that if labor organizations would devote less time and energy to contention with employers and more effort toward making the organization stand for skill and plain, simple honesty in workmanship, and for fair dealing with, and reasonable devotion to, the interests of employers, all questions connected with the recognition of the union would fade into insignificance and collective bargaining would be welcomed, nay, even sought for, by those who are managing the great industries of our modern civilization.

Third, it is evident that the engineer who makes or finally decides upon the design of any structure carries a heavy load of responsibility. He is first in the field and practically tells all who follow what is to be done. He must decide not only the kind of material that is to be used but also the amount or sizes, and how it shall be disposed. His realm embraces every kind of structure, from the foundations of a bridge or building to the most minute detail of a locomotive or car. In railroad track he says or should say what weight of rail shall be used, the number of ties per rail, and the kind and depth of ballast. His knowledge of the properties of materials used on construction must necessarily be broad and comprehensive, and the field is so enormous that there are naturally numerous specialists, each being able to cover, and be an authority in, only his own little paddock.

The engineer who makes the design labors under two very serious difficulties. First, it is not possible, many times, to compute the strains to which the whole or parts of the structure will be subjected. Perhaps we can make this point clear best by considering the locomotive driving axle. The strains produced, when we regard the locomotive as a vehicle, are simple and easily determined. So likewise the bending moment produced by the action of the steam on the piston, as well as the torsion strain produced by the crank. But who can tell the bending moment produced by the lurch when the wheel strikes a curve at high speed? Who can even give a guess at the strain produced when the brake is applied, making an emergency stop at sixty miles an hour? Moreover, the tendency of the times is toward larger and larger structures. And as the parts increase in size, would any of us be willing to say that the strains in each part would increase directly proportional to the increase in size of the whole structure, or that a proportional increase in size of any given part would so successfully meet the increased strains as did the corresponding smaller parts of the original structure? The engineer who makes the design, perhaps more often than any of us, is at the end of his knowledge, and if failure comes due to defective or faulty design deserves, in our opinion, more sympathy than any one else involved.

But the designer labors under another serious difficulty. He is often overruled and prevented from doing what his judgment prompts him to do, in the interests of safety, by those who control expenses. The construction he would like to use costs more, and the management for economic reasons demands something less expensive. Of course, under these conditions, much responsibility is taken off the designer. And while we are ready to allow that some check is desirable, since those who make the design are, after all, human and naturally will take care of themselves, we cannot but feel that this check should be sparingly applied in all places where safety to human life is involved.

Fourth, unfair treatment. As already indicated, there is a natural disposition on the part of each of us to relieve ourselves from blame and put the fault on some one else, and if our observation is worth anything there is no field of parceling out deserts among those involved in failures and the responsibility therefor more fertile than this one of unfair treatment. This field is the especial paddock of the maker or producer of material. If a rail breaks or fails in service there was, says the rail maker, something wrong with the track or with the locomotives or cars that run over it. If a car wheel breaks or fails to give the guaranteed mileage, the track was too rough, the use of the brakes too severe or the lading too heavy, and so on. Far be it from us to say that unfair usage is not many times a legitimate explanation of failures. If a freight locomotive, designed to haul a heavy load at twenty miles an hour is used at times on a passenger train at forty miles an hour, and in so doing shakes herself to pieces, the fault is certainly not in the materials nor in the workmanship, nor in the design, but in the unfair use. If, due to the growth in size of locomotives and cars, an old iron bridge, designed for not over two-thirds the live load which is actually put upon it, gives way and produces a disaster, the responsibility rests with the operating officer rather than with the bridge engineer. These examples might be multiplied to almost any extent, but perhaps enough has been said to make the point clear.

There is, however, another phase of this part of our subject. Unfair treatment is very much broader than the obvious misuse of a bridge or of a moving vehicle. The materials entering into a structure may be unfairly treated. If the calculated strains are too high, or, what amounts to the same thing, too low a factor of safety is employed, materials are unfairly used. Still further, where a structure is a composite it may, and undoubtedly does, often happen that the elements making up the composite are unfairly treated, as when, for economic reasons, not enough money is spent to properly install the structure. For example, a steel rail called upon to do its work supported by too few ties, insufficient ballast and a badly drained sub-grade, is unfairly treated. Moreover, the state of repair in which structures are maintained is clearly an element in their fair treatment. If not enough money is spent in repairs and parts become weakened by decay, corrosion or wear to such an extent that failure results, it is entirely obvious that the failure must be attributed to unfair treatment.

We have gone thus quite at length into detail in what has preceded in order that we might have definitely before us the elements entering into this problem and be able to see more clearly where truth and justice lie between the conflicting interests. If now our analysis of the causes of failure is accepted as correct, it is evident that freedom from failure in construction depends on the conscientious and intelligent action of four different contributors to the final result. The materials employed must be conscientiously and intelligently made, and must be what they are supposed to be. The workmen who use these materials must do their work conscientiously and under intelligent guidance. The engineer who designs the structure must have abundant knowledge of the properties of the materials he is using and must take as little as possible for granted in deciding on shapes, sizes and kind of materials to be employed. And, finally, the one who installs and operates the structure, when it is completed, must keep it in proper repair and look well to it that no duty is required of it which subjects it to unfair strains.

It is likewise evident that, since the four parties involved in successful construction have different individualities and may have diverse and even antagonistic interests, there is abundant reason why there should be an attempt to shift responsibility for failure. And, indeed, we might perhaps safely go a step further and say that there is abundant reason why each of the four parties should try to limit the part which his own work plays in the final result, and say plainly if the other three had done as they should there would have been no failure. The man who furnishes the material is tempted to say, "*If* the designer had allowed a proper factor of safety everywhere, if the workmen had done their duty, and if the structure had received only proper fair treatment, almost any material would have been good enough." The engineer who makes the design is tempted to say, "If the material had been what I had a right to expect it to be, if the workmen had done good work and there had been no abuse of the structure in service, there would have been no failure." And so on, for the others. It is plain that the problem of obtaining successful constructions is a complicated one, and that the chances for divided responsibility which are involved are no small element in this problem.

Within the last few months two episodes have occurred which so clearly illustrate two phases of our theme that we cannot forbear to quote them. The two phases are unfair treatment and the inference that the blame for failure rests on some one else. It will be remembered that within the past two or three years there has been much outcry in regard to broken steel rails, and the steel rail manufacturers have, in the technical press, been quite severely called to account, for their shortcomings. Indeed, from this platform, in the last annual address, some statements were made indicating that it was believed that the maximum fiber stress in the 100-lb. rail under present conditions of wheel loads and speed was not over 12,500 lb. per square inch. Some two months ago we received a letter from one of the ablest metallurgical engineers connected with steel rail manufacture in this country, in which this statement was very seriously called in question. The writer of the letter figured that under many conditions the fiber stress might be double the figure given, and that under extreme, but still possible, conditions the fiber stress might reach nearly four times this figure. The obvious conclusion was, although this was not stated in the letter, that it was these extreme fiber stresses, this unfair treatment, which caused the rails to break. We have tried in vain thus far to get some one much more competent than ourselves to prepare a paper on this subject for this meeting, and one object we have in mind in citing it now is to stimulate study and attention to it. Will not some one take hold of this problem and give it exhaustive treatment, allowing the maximum effect to wheel loads, counter-balance, effect of the steam, want of rotundity, flat spots, nosing and speed? A theoretical treatment, even though we are not all satisfied that the rail acts like a continuous girder supported at the centers of the ties, cannot fail to be valuable.

The other episode is the experience of the Atchison, Topeka & Santa Fe

Railroad with broken rails on different sub-grades. This road had some 227 miles of roadbed which were sandy, porous and well drained, and 91 miles which were largely clay of a kind that holds water. The traffic was the same over both portions and the rail all 85-lb. rail. The rail breakages in one year were two and a half times greater per mile of track on the clay sub-grade than they were on the sandy sub-grade. Mr. Wells, the general manager of the road, was kind enough to say, in communicating this information, that these facts seemed to confirm the statement made in the last year's annual address that "there are indications that rail failures are a question of geography." More to the point for our present discussion is the obvious conclusion that the use of rails on clay sub-grade full of water without sufficient porous ballast is unfair treatment, and that breakages, under such conditions, can not justly be said to be the fault of the rail.

But perhaps we have said enough in analysis of the causes of failure. Let us now devote a few moments to precautions that may be taken with material and workmanship in the interests of safety; and to a consideration of what should be our mental attitude toward design and unfair treatment. And first as to workmanship. Under present conditions the necessity for close supervision is evident. Managing men everywhere recognize this necessity and are employing all means at hand to secure it. We knew an officer of a large corporation some years ago who said to his board of directors: "If you will allow me to spend $50,000 a month more in salaries, so that I may give your work better supervision, I will give it back to you four-fold." Moreover with the growth of modern industry and especially with the development of machinery as an element in this growth, the individuality of the workingmen has necessarily diminished, and the present industrial ferment of strikes and lockouts, with their accompanying riots and violence, is, as we interpret it, the revolt against this debasement of individuality. That the revolt should at times go too far, that unreasonable demands should be made, that demagogues and agitators for their own advancement should get into positions of prominence, is perhaps to be expected. As time progresses these will pass. It takes time to bring a change of views in both employed and employers. Already there are signs of something better and our belief is that in the not far distant future, as the result of wiser management on the part of labor organizations and reasonable concessions on the part of employers, there will be a return by the workingmen to the old-fashioned virtues of interest and pride in their work, and unswerving loyalty to the organizations which they serve. The effect of this change on the quality of workmanship needs no comment.

Second, with regard to material. It is difficult for us to see how any one who is responsible for safety in structures dare at the present time put material into these structures which has not been bought on carefully prepared specifications, and which, before acceptance, has not been rigidly inspected and tested. In time past, before consumers understood the demands which the service makes on materials, the reputation of the maker was perhaps the best safeguard known for good materials and was accepted as reasonable defense in the investigations following disaster. But in these days, when the service has been so frequently questioned, when so much accumulated information is available, when experts and facilities for testing are so largely multiplied, we cannot help feeling that the management that puts materials into service, especially where safety is involved, without careful and conscientious inspection and testing, is taking a risk that it is no longer entitled to assume. It is gratifying to be able to see that, as the years go by, there is constant and steady growth in this field. And while the ground is still far from being covered and the number of standard specifications still far too small, each year brings some progress, some steps forward. This society has a most important mission to fulfill, and the publications of no organization that we know of anywhere are doing more to elevate the standard of quality of materials of construction than the annual volume giving the results of the deliberations of this body.

Third, bad workmanship and bad materials can apparently be so controlled as to secure safety by sufficient supervision and by having proper specifications, with rigid inspection and test. But how about the unfair treatment of materials, or the structures made from them? Here no supervision beyond some meagre legislative enactments and the condemnation of public opinion in case of disaster, is possible. It is, of course, true that those in charge of the construction and operation of utilities in which the public safety is involved are constantly face to face with the possibilities of heavy losses in the way of damages for accidents, and no doubt this is a most powerful check against unfair treatment. But it has seemed to us for a long time that the producers of material have far too much neglected their opportunities. Surely it is as legitimate that the producer should study the treatment his material gets in service as that the consumer should study the methods by which that material is made. It may take the consumer a few years to become familiar with the idea of being told that he has not treated material fairly, since he is undoubtedly accustomed now to thinking that he can do what he wishes with what he has bought and paid for; but we are confident there would have been fewer complaints of material in the past if the method we have suggested had been in vogue. It is, of course, not to be understood that we are recommending howls about unfair treatment as excuses for inferior materials. What we have in mind is that careful studies and investigations should be made by the producer, leading up to demonstrations if possible. It is common experience that the truth is reached with much greater certainty and speed if a problem is attacked by two parties who approach it from different standpoints and are actuated by antagonistic interests. Our whole Anglo-Saxon jurisprudence is founded on this method of procedure.

Fourth, what shall we say of the engineer who makes the design? We have already described his difficulties, pointed out his limitations and expressed our sympathy with him in his chance failures. It remains to put on record a few thoughts which have forced themselves on us, not once but many times, while preparing this paper, as especially when contemplating the difficulties of the engineer who makes the design. The truth is we are using materials in construction without sufficient knowledge. There is crying need for experiment. Testing machines, adequate to cope with some of the problems which now confront engineers, do not exist. We are increasing sizes and constantly building larger structures. If the test of service gives a failure it simply proves that our guess as to the increase needed was wrong; and if the test of service shows freedom from failure we still do not know that we have used material wisely and economically. The factor of safety everywhere is largely a guess. The late A. L. Holly, one of the brightest mechanical engineers in this country twenty-five years ago, used to speak of "the ridiculous factor of safety, one-half of which is a factor of ignorance." We cannot help feeling that no better use could be made of some small fraction of the millions that have been accumulated by individuals in connection with our great industries during the past half-century than in the establishment of a Bureau of Engineering Research. Who will avail himself of this magnificent opportunity?

Just a word in conclusion. No one,

I am sure, can contemplate the situation which we have been trying to discuss without being impressed with the diverse and ofttimes antagonistic interests involved. The producer of material is anxious to secure the largest amount of successful output and the greatest possible amount of reward therefore. The consumer wants to limit this by restrictions as to quality and to obtain the material at the lowest possible figure. The workman's interest is to secure the maximum of pay for the minimum of effort, and in this struggle it may perchance happen that the quality of work suffers. The employer's interests are clearly the reverse of the workman's, and so on. The foundations of these diverse interests are of course very deep, and with the present organization of society it is not easy to see how they are to be obliterated or their antagonism neutralized. But we beg to make one suggestion. Would not an infusion of genuine conscientiousness into our industrial life bring an amelioration? If a little less energy was expended in the mad race for wealth and a little more zeal manifested in maintaining the rugged virtues of honesty, integrity and fair dealing, would not some of the friction and contention of our present commercial life disappear? We must all live together, and surely harmony is better than contention. There are some things in life of more value than money.

Secretary's Trip to the Middle West

In the course of his recent tour of the Pacific coast, Secretary Ralph W. Pope received invitations to visit the Fort Wayne and Chicago Sections on his homeward journey. This being found inexpedient, the suggested visit was postponed until after the November meeting of the Board of Directors. The previous trip having proved so successful, the Board at its meeting held on November 12, 1909, authorized the secretary to visit the Fort Wayne and Chicago Sections, and such other Sections and Branches in the Middle West as might be deemed feasible. Accordingly the secretary left New York on November 14, to be absent about two weeks. The Sections visited were: Urbana, Chicago, Madison, Minnesota, and Fort Wayne. A visit was also made to the Iowa State College Branch, Ames, Iowa. At the time of going to press with this PROCEEDINGS a detailed account of the trip had not been received at Institute headquarters. A more extended report will be published later.

New Branches

At its meeting held on November 12, 1909, the Institute Board of Directors authorized the formation of a Branch at the Agricultural and Mechanical College of Texas, College Station, Texas, and also one at the Rensselaer Polytechnic Institute, Troy, N. Y.

Sections and Branches

UNIVERSITY OF ARKANSAS BRANCH

The University of Arkansas Branch held its second regular meeting on the evening of October 21, 1909. Twenty-eight members and visitors were present. Mr. M. F. Smith reviewed the Institute paper on "Electric-Driven Rolling Mills", presented at the Frontenac Convention. Mr. A. W. Gregg, a member of the senior class, who during the summer months was employed by the Fayetteville Electric Light & Power Company as meter tester, read an interesting paper on "My Experience with Meters." The increase in attendance indicates that the Branch meetings are becoming more popular.

The next meeting of the Branch took place in the engineering hall on Thursday evening, November 4. The principal feature of the program was a paper by Mr. S. B. Graham describing his experience in installing 13,000 feet of telephone cables in Mena, Ark. Mr. P. E. Chandler then reviewed the Institute paper on "Auxiliary Poles for

Direct-Current Machines", presented by Mr. J. N. Dodd at the Frontenac Convention.

ARMOUR INSTITUTE BRANCH

The Armour Institute of Technology Branch held its first fall meeting on October 7, 1909. After the disposal of the usual routine business Chairman E. B. Sherwin introduced the subject of the evening in the form of a paper entitled "The Sprague General Electric Automatic Control." Mr Sherwin first took up the historical side of the subject, including the problems with which the designer was confronted and how the various difficulties had been overcome. He then described in detail the action of the system, and by means of blue-prints gave a thorough explanation of its operation. The application of this method of control on the various elevated railroads of Chicago was discussed, as was also its advantages and disadvantages in comparison with other modifications. Mr. Baer led the discussion which followed.

At the meeting of the Branch held on October 28, Mr. C. C. Bailey presented a paper on "Railway Block Signaling." Mr. Bailey outlined the advancement in this work from the original lever signal to the modern automatic block signal, going very thoroughly into the details of the construction and operation of the systems in use at the present time. He laid considerable stress on the installation of the alternating-current single-rail system as used on direct-current lines. The talk was supplemented by diagrams and data illustrating the saving due to decrease in accidents and the lower cost of operation of modern systems. The discussion which followed indicated the keen interest taken in the subject.

BOSTON SECTION .

An unusually large number of members of the Boston Section were present at its first meeting on Wednesday evening, October 20, in the auditorium of the Edison Building. Chairman D. C. Jackson presided. The question of local membership was brought up for discussion and it was voted that such a membership be established, the annual dues to be $1.00 per year to persons not Institute members.

Mr. John B. Taylor, of the General Electric Company, Schenectady, presented his recent Institute paper entitled "Telephone and Telegraph Systems as Affected by Alternating-Current Lines." Considerable discussion followed.

CHICAGO SECTION

A joint meeting of the Chicago Section and the Electrical Section of the Western Society of Engineers was held in the rooms of the latter on October 22, 1909. About 200 engineers were present to hear an address by Mr. W. L. Abbott, chief operating engineer of the Commonwealth Edison Company, on "Central Station Economics." Mr. Abbott spoke of the wonderful development of the electric lighting industry in Chicago during the last 10 years. He made an interesting analysis of the factors entering into the cost of generating and transmitting electrical energy. The paper was ably discussed by those present. Among the members taking part in the discussion were: J. G. Wray, R. F. Schuchardt, A. Bement E. N. Lake, R. H. Kuss, O. E. Olsen, W. E. Keily, G. H. Jones, J. H. Warder, D. W. Roper, and Mr. Abbott.

CLEVELAND SECTION

Professor Gartley, of the Illuminating Engineering Society, and Mr. McBeth, gas expert of Philadelphia, were guests of the Cleveland Section at its first meeting, which was held on October 18, 1909, and an interesting program attracted a large audience, there being a total attendance of 140.

The first paper of the evening was presented by Mr. J. D. Hoyt, of the National Electric Lamp Association on the subject of "Street Illumination."

It proved of exceptional interest, as it dealt with foreign practice as well as that in this country, from an early date down to the present time. Mr. Hoyt's talk showed an extensive knowledge of the subject and careful work in the collection of the data.

Professor Gartley's address was of an informal nature, and dealt with the advance of gas for street illumination in this country within the last few years. The subject of application and control of high-pressure gas systems evoked much interest.

Mr. McBeth gave his attention to lighting from ornamental street posts by gas and by tungsten lamps.

Mr. Eshelman presented some fine views of existing and proposed tungsten installations and series and parallel lighting on ornamental fixtures and boulevard posts.

The Section officers were very much encouraged by the large attendance at this meeting.

IOWA STATE COLLEGE BRANCH

The Iowa State College Branch held its first meeting for the college year on October 6, 1909, the attendance numbering 22 members. Mr. H. H. Wagner presented a paper on " Electricity and the Conservation of Energy," based on the Institute paper by Mr. Lewis B. Stillwell, relating to the same subject. Mr. Wagner illustrated by means of curves the rate of depletion of the coal supply of the world, and also showed the relative increase of water power over that of steam.

Mr. Mason then abstracted the Institute paper of Mr. J. N. Dodd, presented at the Frontenac Convention, entitled " Auxiliary Poles for Direct-Current Machines."

A short business meeting concluded the program. Mr. R. B. Gray's resignation from the executive committee was accepted; and Mr. Jerome A. Noble was elected to succeed him.

The second meeting of the Branch was held on October 20, and was one of the most enthusiastic and successful in its history. One hundred and five members and visitors assembled to hear a lecture by Dr. E. M. Stanton, of Schenectady, N. Y., on the " Cause of Death from Electric Shock and Resuscitation from Shock." Dr. Stanton, who is an alumnus of the Iowa State College, was warmly welcomed, particularly by the electrical engineers. Having made a special study of the effect of severe shocks, his lecture proved very interesting.

Another paper on the " New Electrical Engineering Laboratory at Iowa State College" was presented by Professor Adolph Shane. Professor Shane gave an outline of the plan and wiring of the new laboratory, which is one of the best in the country. Power from both alternating- and direct-current circuits is obtained through a motor-generator sub-station set. The driver is a 100-h.p., three-phase, 1100-volt induction motor, adjusted to two per cent slip at full load. On the same shaft with this motor is a 60-kw., direct-current, 125-volt, generator, a 50-kw., three-phase, 110- and 120-volt, 60-cycle, alternating-current generator and exciter. Controlling this set is a switchboard with a separate panel for each machine, and Tirrill regulators for the alternating-current and direct-current generators. The laboratory is equipped with individual drive units averaging 7.5 kw. or 10 h.p. Each unit has its own switchboard with all the necessary instruments and controlling apparatus mounted thereon, but no instrument or apparatus is connected up, that being left to the care of the student by means of plugs and jacks. The wiring is all done in trenches running in both directions of the laboratory.

ITHACA SECTION

Seventy-five members attended the meeting of the Ithaca Section held on October 15, 1909, the first gathering of the season. A committee was appointed to confer with the local branch of the American Society of Mechanical Engineers with a view to the coöperation of the two organizations. The following Institute papers were reviewed: "Output and Regulation in Long-Distance Lines", by P. H. Thomas, abstracted by J. F. Putnam; "Calculation of Iron Losses in Dynamo Electric Machinery", by I. E. Hanssen, abstracted by E. C. Horton; "Multispeed Induction Motors", by H. G. Reist and H. Maxwell, abstracted by H. C. Boos.

At the November meeting, held on November 5, there was an attendance of 93. The following committees were appointed: Membership, Meetings and Papers, Publicity, and Special. Professor Norris delivered an address on "High-Tension Phenomena", which he illustrated with experiments.

UNIVERSITY OF KANSAS BRANCH

The regular monthly meeting of this Branch was held on October 6. At this meeting officers for the ensuing year were elected as follows: Chairman, V. S. Foster; vice-chairman, F. P. Ogden; secretary and treasurer, R. L. Ponsler, executive committee, G. C. Shaad, Glen Morris, H. A. Hoffman, and L. A. Baldwin. Following the election, Professors M. E. Rice, C. A. Johnson, and R. M. Freeman each gave a brief talk on the purposes of Branch meetings and their advantages to the students. There was an attendance of 27 members and enrolled Students.

The second regular meeting was held on October 19, with a total attendance of 28. Professor G. C. Shaad gave a talk on "A Modern Railway Traffic Study." Some discussion followed Professor Shaad's remarks.

LEHIGH UNIVERSITY BRANCH

The second regular monthly meeting of the Lehigh University Branch was held in the physics laboratory on the evening of November 9. The program consisted of three papers, as follows: "Testing of Direct-Current Machinery", by Mr. J. S. Rowan. "Life of Lord Kelvin", by Mr. C. A. Faust. Mr. Faust paid a pleasing tribute to the late Lord Kelvin. The last paper of the evening, "Magnetic Theory of Alternator Regulation", presented by Professor S. S. Seyfert, gave a very interesting insight into his field of investigation during the past year. In conjunction with Mr. W. H. Lilich, Professor Seyfert made some tests on alternator regulation. Sixty two members were present.

LEWIS INSTITUTE BRANCH

The Lewis Institute Branch began its third year of activity with a meeting on November 3, 1909. The meeting was a decided success, and was attended by nearly 400 engineering students, who gathered to hear a talk by Mr. A. D. Bailey, of the Commonwealth Edison Company, on "Central Station Operation in Chicago." Mr. Bailey remarked the rapid development of central stations throughout the country, and emphasized the growth of central stations in Chicago. The Fisk Street and Quarry Street stations were cited as examples of the most modern stations extant, and some interesting figures concerning their operation were given. The boiler rooms of these two stations contain 104 boilers, with a total heating surface of nearly 14 acres, capable of evaporating over 2,500,000 lb. of water per hour, and converting it into steam at 200 lb. pressure and 150 degrees superheat. This requires nearly 50 carloads of coal per day. The coal used is commonly known as Illinois screenings. It is taken from the cars and transported to the bunkers over the boilers where it is fed into the furnaces by means of mechanical stokers and chain grates. The ash drops from the end of the grate and is taken away in the outgoing cars. The turbine room contains 13 turbine-generators of a total capacity of 215,000 h.p. Each turbine comprises a complete station in itself, having its own set of boilers, condensing system, coal-handling machinery, and boiler-feed piping, thus carrying out the unit system to the most minute detail. Each unit is in this way entirely isolated from every other unit, which greatly facilitates the operation of the station and minimizes the danger of mistakes and accidents. The current is generated at a pressure of 9,000 volts and is transmitted to the switch-house. The operation of the switches in the switch-house is carried on from the operating gallery in the turbine room, with the remote-control system. No pressure therefore exists on the operating board over 110 volts. From the switch-house the current is distributed to the various sub-stations of the company.

LOS ANGELES SECTION

This Section held its first business meeting of the year on Tuesday, October 26, 1909. The executive committee having secured a suitable downtown meeting place in the Blanchard Building, the attendance at meetings has been stimulated greatly. Eighty-two members and visitors were present at this meeting.

A paper was presented by Mr. Clem A. Copeland, on " The Life Hazard and Resuscitation in Electrical Engineering." Many points were brought out in the paper seldom touched upon by other investigators in this line. Dr. Milbank Johnson, director of the Pacific Mutual Life Insurance Company, and Dr. H. C. Stinchfield, chief surgeon for the Southern California Edison Company, were present, and participated in an interesting discussion. Messrs. E. R. Northmore, J. A. Lighthipe, F. P. Walton, and R. H. Manahan discussed the paper from an engineering point of view.

MEXICO SECTION

The members of the Mexico Section gathered at a banquet on October 22, 1909. The annual election of officers took place at this meeting. Mr. E. Leonarz was elected chairman, and Mr. W. A. Ferguson secretary. The executive committee for this year is constituted as follows: Gustavo Lobo, H. S. Foley and A. E. Reynolds. Mr. William B. Hale, who represented the Section at the Frontenac Convention, entertained those present with a report of the proceedings at the convention, and abstracts of some of the papers read on that occasion.

MONTANA AGRICULTURAL COLLEGE BRANCH

The first meeting of this Branch for the year was held on October 13, 1909, and was devoted exclusively to business. There was an attendance of 22, with Mr. C. C. Kennedy presiding. Chairman Kennedy was instructed to appoint a committee to draft a new set of by-laws, also to appoint a program committee. In conclusion several short talks were given by Messrs. Kennedy and Thaler in regard to the benefits to be derived from membership in the Branch.

At the meeting of the Branch held on November 12, 1909, Mr. Floyd Lorentz addressed the members on the general subject of electrical apparatus and machinery. Mr. Lorentz gave some useful information on drying out water-soaked eletrical apparatus and the repair of transformers. He also gave a description of the machinery used in mines, concluding his remarks with an account of the lime-method of drying transformer oil.

OHIO STATE UNIVERSITY BRANCH

The Ohio State University Branch resumed its activities at a meeting held on October 20, 1909, at which 40 members were present, with President G. A. Arnold in the chair. Executive business was postponed until the next meeting. Professor F. C. Caldwell gave a talk on arc lights, and a demonstration of the magnetite and flaming arc.

OREGON AGRICULTURAL COLLEGE BRANCH

The Oregon Agricultural College Branch started the year 1909–1910 under favorable conditions at a meeting held on November 4, 1909, there being an attendance of 46 members and visitors. The election of officers showed the following result: President, E. R. Shepard; secretary, W. Weniger; board of directors, T. M. Gardner, S. H. Graf, E. V. Hawley, C. L. Knopf, E. R. Shepard, W. Weniger.

Dr. Weniger led an informal discussion on the subject of electromagnetic induction, at the conclusion of which refreshments were served.

PHILADELPHIA SECTION

The regular monthly meeting of the Philadelphia Section was held on November 8, 1909, with Professor George A. Hoadley presiding. Dr. William McClellan, of New York City, presented a paper entitled " The Community's Estimate of the Engineering Profession." Those who discussed the paper were Messrs. Hoadley, Stevens, Spencer, Sanville, McLeod, Hornor, Green, Israel, Day, Furber and Dr. McClellan.

PITTSBURGH SECTION

The Pittsburgh Section held its regular meeting in the Carnegie lecture room on Tuesday, November 9. The following papers were presented: " Applications of Concrete to Central Station Systems ", by H. N. Muller; " Uses of Reinforced Concrete in Railway and Power-house Work ", by F. W. Scheidenhelm, consulting construction engineer; " Concrete Construction in European Power Plants ", by S. Q. Hayes.

Mr. Muller described some reinforced concrete slab construction for switchboard work and also for the construction of semi-portable transformer houses to be placed in basements and at the rear of stores and factories.

Mr. Scheidenhelm showed a number of pictures of power-house and bridge construction as used by the West Penn Railways Company.

Mr. Hayes gave a description of concrete construction in sub-stations as seen by him throughout Europe.

Mr. W. M. Kinney, of the Universal Cement Company, and Mr. B. P. Rowe contributed discussion on the papers presented. Ninety-eight members attended the meeting.

PITTSFIELD SECTION

Dr. C. P. Steinmetz, of Schenectady, was the guest of the Pittsfield Section at its first meeting for the year, held at the Wendell Hotel on November 4, and 200 members and visitors assembled to hear his lecture on " The Law of the Conservation of Energy." Dr. Steinmetz mentioned as two of the great laws of nature the law of conservation of matter, and the law of conservation of energy. The former, he stated, has existed for several centuries, but the idea of the latter has been conceived during the last 75 years. That all forms of energy, whether existing as mechanical motion, light, heat, electricity, or chemical affinity, are convertible, one into the other, and that whatever the amount of energy started with must be accounted for in one of these forms, is universally accepted by scientific men, yet the direct application of this theory to problems in engineering is not made to nearly the extent that it could be with great advantage. Many problems which without the application of this law are extremely complicated, would be very much simplified and more easily solved. Dr. Steinmetz illustrated this point by an experiment with a horse-shoe magnet attracting a bar of iron, showing that the electrical energy made use of by the magnet during the motion of the bar could be obtained by finding the voltage induced in the magnetic coil, caused by the change in the position of the bar from its initial to its final position and multiplying by the current which was flowing. Dr. Steinmetz cited several examples of tests of electrical machinery in which this law is made direct use of. He again illustrated the use of the law in the calculation of the mechanical forces of repulsion or attraction which exist between two large parallel conductors carrying heavy currents, the attraction or repulsion depending upon whether the current is flowing in the same or in the opposite direction in the two conductors. Under short-circuit conditions these forces may be sufficiently great to tear the conductors from their fastenings. Without the use of this law the calculation of the forces involved for a given arrangement of conductor carrying a given current would be extremely difficult. The most interesting application of this law made by Dr. Steinmetz was in the calculation of the forces which may develop between the primary and secondary coils of a transformer when short-circuited. In this case he assumed a shell type transformer of 5,000 kw. capacity, having a four per cent reactance and negligible resistance. When the transformer is short-circuited, 25 times more full load current will flow, and the magnetic flux, which under normal conditions links both primary and secondary windings, must, therefore, under short-circuit conditions, pass through the space between the primary and secondary windings as leakage flux. Assuming the secondary coil to be moved from its position towards the primary until it becomes coincident with the primary coil, it would during the movement cut all the magnetic flux and therefore during the time of motion have induced in it a definite voltage.

Asked as to whether the recent discoveries of radium phenomena did not upset the stability of the law of conservation of energy, Dr. Steinmetz replied that there are two ways of explaining the phenomena without confuting the law. First, that since the deductions in regard to the properties of radium are based on experimental work on very minute quantities of the substance, involving exceedingly small measurements, the probability of gross errors in deductions is great. Secondly, assuming that the deductions are correct, the liberation of the vast quantity of energy by radium can be explained by the breaking down of the atomic structure of radium, as large amounts of stored up energy can be liberated by the explosion of dynamite due to the re-arrangement of the material of which the dynamite is composed. He stated that the law of conservation of energy would not be shaken by this means until a piece of radium were shut up in a place where it could not receive energy from the outside, and the energy given off for several centuries were measured, and it could then be verified that the radium had not been changed in any way while giving off this energy.

PORTLAND SECTION

The Portland Section opened its work for the year 1909–1910 at a meeting held on Tuesday evening, October 19, 1909, 40 members being present. Having outgrown its former quarters at the Sherlock Building, the meeting place has been changed to the Knights of Pythias Hall.

Secretary L. B. Cramer, the Section's delegate to the Frontenac Convention, made a report of the convention, after which the Institute paper by Mr. B. R. Shover, on the Gary steel plant, was reviewed and discussed. Arrangements will be made for the presentation of local papers at future meetings.

PURDUE UNIVERSITY BRANCH

The Purdue University Branch has commenced its work for this year under a new policy which permits the admission of lower classmen as members of the Branch. Formerly the membership was composed of upper-classmen only. The first meeting of the Branch was held on Tuesday, September 28, and over 100 men were present. The new policy of the Branch was explained by the local officers, and received the hearty endorsement of those in attendance.

Professor C. F. Harding spoke of the advantages of affiliation with the Institute. Professor H. T. Plumb and Messrs. C. R. Moore and V. D. Cousins endorsed Professor Harding's remarks. The meeting was an informal one.

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The first regular meeting was held on Tuesday, October 12. The topic of discussion was a paper on " Railway Auto Cars ", presented by Mr. J. M. Drabelle. Mr. Drabelle's experience had been acquired in connection with the Rock Island System, and he dealt mainly with the gasolene-electric car employed by them. This car has been found very efficient on small branch lines feeding main trunk lines, where it can perform the same work done by steam locomotives, and can do it more economically. The elimination of dirt and smoke by its use makes it a factor worthy of consideration in the electrification of roads where dirt and smoke must be eliminated, but where circumstances will not immediately permit complete electrification. The car is operated by electric power from a generator directly connected to a gasolene engine in the forward part of the car.

Mr. C. R. Moore gave a talk on " How to Study." He suggested optimism, keeping busy, working at " full load," and enough outdoor work to keep the mind well balanced.

Mr. C. F. Pittman gave a review of recent railway journals, discussing electrification in a general way.

San Francisco Section

On October 29, 1909 the San Francisco Section held its first meeting in the new quarters given to it by the Home Telephone Company. Through the generosity of Messrs. McMeen and Miller, the meeting room was furnished with chairs, tables, lantern, and blackboard. It has a seating capacity of 300, and is well ventilated and lighted. By unanimous resolution a vote of thanks was extended to the donors.

Messrs. Hilton and Charters presented a paper on " Some Phases of Transformer Regulation ", which graphically showed the troubles that are often encountered in the connection of transformers when operated under certain conditions. Professor Harris J. Ryan, Professor Cory, Messrs. Lamme, Lee, Holberton, Hall, and Geibel took part in the discussion. The attendance numbered 73 members and guests.

The executive committee of the Section as now constituted is as follows: Chairman, George R. Murphy; secretary S. J. Lisberger; C. W. Burkett, S. G. McMeen, Wynn Meredith.

Schenectady Section

On November 2, Dr. C. P. Steinmetz addressed the Schenectady Section on " The Standardization Rules of the American Institute of Electrical Engineers." Dr. Steinmetz opened his lecture by stating that the reason he selected the standardization rules as the topic for the evening was on account of their importance to the electrical profession in general, and because the rules are not so well known to many electrical engineers as might seem desirable. He expressed the opinion that the standardization rules represent the most important work the Institute has ever undertaken, and constitute one of the most important documents in electrical engineering literature. He said, further, that at the present time it is hard to realize the importance of the rules unless one recalls the conditions which existed in the manufacture of electrical apparatus before the adoption of the rules by the Institute. He then pointed out how conditions have changed to the advantage of the electrical industry and the profession in general. Many interesting points in the rules were brought out in the course of Dr. Steinmetz' talk.

A short discussion, with a few remarks from Chairman Troy on the plans of the Section for the future, concluded the program. There was an attendance of between 500 and 600 members.

Seattle Section

The Seattle Section held its regular monthly meeting on October 16. This being the closing day of the Alaska-

Yukon-Pacific Exposition, the attendance at the meeting was somewhat smaller than usual. Thirteen members, however, were present. The reading of the minutes of the May meeting was followed by a discussion of the joint sessions of the Section with the Northwest Electric Light and Power Association at the exposition on September 7, 8 and 9, and a vote of thanks for the courtesies extended to members of the Section was directed to be transmitted to the Northwest Association.

Professor C. E. Magnusson presented his report as delegate of the Section to the Frontenac Convention, and gave a sketch of the business and social features of the meeting, also a description of the beauties of the Thousand Islands.

Before adjournment there was some discussion of plans for increasing the attendance at meetings with a view to surpassing last year's record.

SYRACUSE UNIVERSITY BRANCH

The regular monthly meeting of the Syracuse University Branch was held on Thursday evening, October 28. Mr. W. P. Graham presided. Mr. F. Creedy gave the theory of the construction and operation of the adjustable-speed, single-phase shunt motor. A paper on this subject was presented by Mr. Creedy at the Frontenac Convention.

The November meeting was held on Thursday evening, November 11. Mr. A. J. Faulder presented a paper on " Experiences in Telephone Work." The paper dealt particularly with methods employed in determining the probable amount of business in new districts and the laying out of new lines.

The regular meetings of the Branch will hereafter be held on the second Thursday evening of each month.

UNIVERSITY OF TEXAS BRANCH

The annual election of officers of the University of Texas Branch was held at its first meeting for the year 1909–1910, on October 21, 1909. The following officers were elected for the ensuing year: President, B. E. Kenyon, secretary and treasurer, J. A. Correll; executive committee, E. Battersby, J. E. Meadors and G. E. Schultz. The annual report for the year 1908–1909 was read and accepted. The report showed an increase in the membership of the Branch.

TOLEDO SECTION

An interesting meeting of the Toledo Section was held on November 5, 1909. Mr. T. J. Nolan, operating engineer at the Water Street power station of the Toledo Railways & Light Company, outlined the growth of the station since it was established 13 years ago. During this period its output has increased nearly 400 per cent, while changes in the character of equipment have been and are still constantly being made to keep abreast with modern practice. To better illustrate the subject a large number of lantern slides were used, enabling Mr. Nolan clearly to indicate the apparatus discussed. At the conclusion of the talk many of the members and their friends availed themselves of Mr. Nolan's invitation to visit the plant and witness the operation of the station.

The meeting was exceptionally well attended, over 100 members and visitors being present.

TORONTO SECTION

At the first meeting of the Toronto Section, held on October 15, 1909, the secretary submitted the report of the recent balloting for nominations for the current year. The slate as prepared from these nominations was accepted by vote, resulting in the election of the following officers: Chairman, H. W. Price; vice-chairman, E. Richards; executive committee, A. L. Mudge, R. G. Clarke, H. A. Moore, F. A. Gabney; secretary, W. H. Eisenbeis.

Following the announcement of the election, Chairman Price introduced the speaker, Mr. A. J. Soper, who presented a paper on " Transmission-Line Calculations." Among those who participated in the discussion were, Professor Rosebrugh, Messrs. Ashworth, Price, and Black.

URBANA SECTION

The Urbana Section held its opening meeting of the season on October 13, 1909. The following officers were elected for the current year: President, Dr. Charles T. Knipp; secretary, Professor J. M. Bryant; treasurer, H. H. Reeves. There was an informal discussion concerning plans for the coming year. It was decided to arouse interest in the Section's work by the presentation of original papers of Institute standard, also some which would be of still more interest to the junior and senior students.

WASHINGTON SECTION

At the October meeting of the Washington Section Major George O. Squier gave a talk upon " A Vibrating Incandescent Lamp ", accompanying his remarks with demonstrations. He first discussed the carbon filament as a pendulum, and then proceeded to show that by placing the lamp in a magnetic field under appropriate conditions the line source could be spread out into a ribbon of light, thereby reducing the intrinsic brilliancy and making shades and frosting unnecessary.

Major Squier was followed by the secretary of the Institute, Mr. Ralph W. Pope, who stopped over for the meeting en route for home after an extended tour of the Pacific coast. Mr. Pope gave a description of his trip. Refreshments were served at the conclusion of the program.

WASHINGTON UNIVERSITY BRANCH

This Branch held its first meeting of the school year 1909–1910 at the home of Professor A. S. Langsdorf, on the evening of October 21. The result of the annual election of officers was as follows: Chairman, H. F. Thomson; secretary-treasurer, George W. Pieksen. A committee was appointed to report on the advisability of holding evening meetings instead of afternoon meetings.

Professor Langsdorf then gave an informal talk on " Lightning-Causes and Effects." A general discussion followed, after which refreshments were served.

WORCESTER POLYTECHNIC INSTITUTE BRANCH

On the evening of October 22 this Branch was addressed by Mr. W. T. Goddard, electrical engineer for the Locke Insulator & Manufacturing Company, on the subject, " Some Recent Developments in High-Voltage Line Insulation." At the beginning of his talk Mr. Goddard explained the relative merits of glass and porcelain for insulating material, showing why the latter is preferable for high-tension work, and after brief consideration of the materials used in the manufacture of this substance, which are principally clay, feldspar, and flint, the process of manufacture was described with the aid of a number of lantern slides. The method of testing the finished product was shown, and some of the difficulties met with were explained. Reasons were given for the forms of construction employed in the various types of line insulators. The relative merits of the suspension and pin-type forms were pointed out, and the structural features of each were described by means of sketches. In taking up later the line construction which demands such insulators, Mr. Goddard showed a number of types of pole lines in use, explaining the weak and strong points in each. A number of special types of insulators were also shown, together with several methods of passing high-tension lines through the walls of power stations. In the course of the discussion at the conclusion of the lecture Mr. Goddard spoke briefly of some work on wireless telegraph circuits with which his company has been connected. Sixty members and visitors were present at the lecture.

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Personal

Mr. D. W. MacLean has accepted the principalship of the Alton High School, Alton, N. H.

Mr. A. A. Hall has recently been appointed electrical superintendent of the Union Utilities Company at Morgantown, W. Va.

Mr. L. M. Wright, chief electrician, U. S. N., was transferred on October 30 from the U. S. naval station at New Orleans to the U. S. S. New York.

Mr. Guy M. Laird, formerly of Pittsburgh, Pa., is now sales engineer in the Denver district office of the Westinghouse Electric and Manufacturing Company.

Mr. E. A. Loew, for three years instructor in electrical engineering at the University of Wisconsin, has resigned to accept a similar appointment at the University of Washington, Seattle, Washington.

Mr. Ernst J. Berg has withdrawn from the General Electric Company at Schenectady to accept the appointment of professor of electrical engineering at the University of Illinois.

Mr. Humberto Fonts having completed his studies at Columbia University, receiving the degree of electrical engineer, sailed on November 13 for his home in Havana, Cuba.

Mr. George F. Atwater has been transferred from the repair shops of The Connecticut Company, New Haven, Conn., to the operating department of the same company at South Norwalk, Conn.

Mr. Fred S. Clevanger has been transferred from chief foreman of cable construction, Brooklyn, N. Y., to district inspector, Nassau County, New York Telephone Company, with headquarters at Mineola, N. Y.

Mr. R. F. Monges, who was assistant electrical engineer of the San Francisco office of the General Electric Company, has been transferred to Portland, Oregon, as engineer of the Portland office.

Mr. Claude M. Janes resigned his position with the Connecticut River Power Company on October 1, 1909, to enter the construction department of the General Electric Company at Schenectady.

Mr. H. A. Hornor, electrical engineer of the New York Ship-building Company, Camden, N. J., has changed his place of residence from Riverton, N. J., to Hamilton Court, Thirty-ninth and Chestnut streets, Philadelphia, Pa.

Mr. Louis F. Blume, instructor in the experimental engineering department at Cornell University, has accepted a position in the transformer engineering department of the Pittsfield works of the General Electric Company.

Mr. Albert D. Rickenbacher has entered the employ of the postal department at the Washington, D. C. post office, as electrical machinist, and has changed his place of residence to 633 Keefer Place, N. W., Washington.

Mr. C. McCarthy Jones has gone to India to look after the interests of the General Electric Company in that country. Mr. Jones was formerly with the British Thomson-Houston Company at Rugby, England.

Mr. Fred H. Powell, of Germiston, Transvaal, South Africa, has been appointed assistant construction engineer of the Victoria Falls Power Company, Ltd., Germiston, with charge of the eastern district of the Witwatersrand.

Mr. Trygve Jensen, who last year was assistant in electrical engineering at the University of Illinois, is now with the Shawinigan Water & Power Company, of Montreal, Canada. His address is Box 54, Station B, Montreal, P. Q.

Mr. F. E. Boyd, formerly of Brooklyn, N. Y., and for a number of years connected with the General Electric Company at Lynn, Mass., is now engaged on the construction of a hydroelectric and irrigation project in northern Washington.

Mr. H. R. Stuart having resigned his position with the Radio Telephone Company, of New York, is now connected with the sales and engineering departments of the H. S. Sands Electric & Manufacturing Company, with headquarters at Wheeling, W. Va.

Mr. L. Ettrup has severed his connection with the Ashburton Mining Company and Marysville Dredging Company and has opened an office at 864 Pacific Building, San Francisco, as consulting engineer on placer mining and construction of gold dredges.

Mr. George R. Murphy, until recently engineer of the construction and operating departments of the San Francisco office of the Electric Storage Battery Company, has joined Pierson, Roeding and Company, of San Francisco, in the capacity of sales engineer.

Mr. L. L. Gaillard, recently electrical engineer of The Connecticut Company, New Haven, Conn., has assumed the management of The New England Engineering Company, which has established an office in New Haven for the conduct of a general engineering and contracting business.

Mr. Paul L. Faber, formerly mechanical engineer in charge of design and construction, Sanitary District of Chicago, has become designing engineer of the rotary blower compressor and centrifugal pump department of Brown, Boveri & Company, Baden, Switzerland.

Mr. H. D. Penney, until lately tool designer with the Overland Automobile Company, Toledo, Ohio, has accepted a position in the tool designing department of the National Cash Register Company, at Dayton, Ohio, where he will make a specialty of high grade tool and fixture work.

Mr. S. R. Blakeman, a graduate of Purdue University, class of 1909, and recently connected with the Canton Electric Light and Water Works, at Canton, Miss., as chief electrician, has been appointed superintendent of the Senatobia light and water plant at Senatobia, Miss.

Mr. Edward P. Thompson, registered patent attorney, has removed his main office to Washington, D. C., in order that he may be near the Patent Office for the benefit of his clients. Mr. Thompson recently returned from a business and pleasure trip of seven months in Europe.

Mr. E. A. Löf, who for the last six and a half years has been connected with the power apparatus engineering department of the Western Electric Company has accepted a position in the power and mining engineering department of the General Electric Company, Schenectady.

Mr. O. S. Morb, formerly in the engineering department of the Western Electric Company, has resigned his position to become chief engineer of Fairbanks-Morse Electrical Manufacturing Company, Indianapolis, Ind., succeeding Mr. B. F. Bailey, who recently re-joined the faculty of the University of Michigan.

Mr. J. Lebovici, who for the last two years has been chief engineer with the Ideal Electric & Manufacturing Company, Mansfield, Ohio, is now in the engineering department of the Westinghouse Electric and Manufacturing Company. Mr. Lebovici's address is P. O. Box 95, Wilkinsburg, Pa.

Mr. V. J. Diefenderfer, who for the past three years has been associated with the Allis-Chalmers Company, the last year as their Birmingham office manager, has severed his connection with that company to accept a position as sales engineer of the Hardie-Tynes Manufacturing Company, Birmingham, Ala., with headquarters at their home office in that city.

Mr. Earle Jackson Banta resigned on October 19, 1909, his position as mechanical engineer of the Isthmian Canal Commission and Panama Railroad and Steamship Lines, and accepted the appointment of chief engineer of The Cincinnati Equipment Company and The Ohio Steam Shovel & Dredge Company, the plant of the latter company having been merged with that of the former. His headquarters will be in Cincinnati.

Mr. M. C. Turpin, formerly superintendent of the Auburn (N. Y.) Light, Heat and Power Company, and more recently with the Public Service Commission First District, New York City, as electrical engineer, severed his connection with the commission on October 1 to accept a position as technical writer in the publication department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Mr. R. D. DeWolf, who for some years has been connected with the engineering department of the Westinghouse Electric and Manufacturing Company, has resigned his position to become assistant mechanical engineer with the Rochester Railway & Light Company, Rochester, N. Y., where he will have charge of the development of semi-isolated steam heating and generating plants in connection with the company's central station work.

Dr. Samuel Sheldon was the guest of honor at a dinner of welcome given him at the Hotel Brevoort on November 3 by the students of the elctrical engineering department of the Brooklyn Polytechnic Institute. Among the guests were President Atkinson and Professors Chittenden and Green, of the faculty, and President Lewis B. Stillwell and Secretary Ralph W. Pope, of the American Institute of Electrical Engineers.

Mr. H. S. Sladen, who for several years was associated with the Portland Railway, Light & Power Company, Portland, Oregon, as transmission engineer, resigned on September 1 to accept a position with the Electric Bond & Share Company, New York City. Mr. Sladen is temporarily located with the Edison Light & Power Company, Wichita, Kansas, one of the properties of the Electric Bond & Share Company, where he is superintending the work of extensions to their plant and system.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Railway Association. Statistical Bulletin no. 56, 57, 57-A. Chicago, 1909. (Gift American Railway Association.)

American Society of Engineering Contractors. Journal. June 1, 1909—Volume I. New York, 1909. (Gift.)

Annuaire du Bureau des Longitudes. 1910 Paris, 1910. (Gift.)

Application of Niagara Light, Heat and Power Company for Authorization to Issue Bonds to the Amount of $50,000 Opinion of the Commission. n. p. 1909. (Gift of New York State Public Service Commission, Second District.)

Application of the Nassau Electric Railroad Company for the Approval of a Proposed Issue of 730,000 par Value of Bonds under the First Consolidated Mortgage (Case no. 1163) New York, 1909. (Gift of New York State Public Service Commission, First District.)

Canadain Electrical Association. Proceedings of 18th Annual Convention. June 17-19, 1908. Toronto, 1908. (Gift of Association.)

Civil Engineer's Pocket-Book. 19th edition. By J. C. Trautwine. New York, J. Wiley & Sons, 1909. (Gift of J. C. Trautwine, Jr., and J. C. Trautwine 3d.)

Complaint of C. E. Wheaton Against Elmira, Corning and Waverly Railway. Opinion of the Commission. n.p. 1909. (Gift of New York State Public Service Commission, Second District.)

Concrete. By J. C. Trautwine, Jr. and J. C. Trautwine, 3d. New York, J. Wiley & Sons, 1909. (Gift of J. C. Trautwine, Jr., and J. C. Trautwine, 3d.)

Delays to Passenger Trains. Bulletin nos. 16 and 17, n. p. 1909. (Gift of New York State Public Service Commission, Second District.)

Design of Submarines. By M. F. Hay. (From Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

The Dynamo. Its Theory, Design and Manufacture. Volume 1-2, edition 5. By C. C. Hawkins and F. Wallis. London, Whitaker & Company, 1909. (Gift of The Macmillan Company.) Price, $5.50 net.

Contents.—Volume I, Chapter I.—Introductory. Chapter II.—Magnetic Field. Chapter III.—Magnetic Circuit and Its Lines of Flux. Chapter IV.—Production of an E.M.F. Chapter V.—Magnetic Pull. Chapter VI.—Self-Induction and Alternating Current Phenomena. Chapter VII.—Classification of Dynamos. Chapter VIII.—Heteropolar Alternators. Chapter IX.—Homopolar Alternators. Chapter X.—Open-Coil Armatures. Chapter XI.—Closed-Coil Armatures. Chapter XII.—Magnetic Properties of Iron. Chapter XIII.—Continuous-Current Armatures. Chapter XIV.—Field-Magnets. Chapter XV.—Ampere-Turns of the Field. Chapter XVI.—Series, Shunt and Compound Winding. Volume 2.—Chapter XVII.—Armature Reaction in Continuous-Current Dynamos. Chapter XVIII.—Commutation and Sparking at the Brushes. Chapter XIX.—Heating of Dynamos. Chapter XX.—Design of Continuous Current Dynamos. Chapter XXI.—Working and Management of Continuous-Current Dynamos. Chapter XXII.—Armature Winding of Alternators. Chapter XXIII.—Armature Reaction in Alternators. Chapter XXIV.—Construction of Alternator Armatures and Field Magnets. Chapter XXV.—Alternator Design. Chapter XXVI.—Working of Alternators in Parallel. Chapter XXVII.—Descriptions of Typical Dynamos.

Effect of Parallel Middle Body Upon Resistance. By D. W. Taylor (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Encyclopedia Pratica per le Industrie Galvanoplastiche. By P. Conter. Milano, U. Hoepli, 1909. (Gift of publisher.) Price, 5.50 lires.

Evolution of Screw Propulsion in the United States. By C. H. Cramp. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Expenditure of Public Money. Editorial from the San Francisco

"Chronicle" Monday Aug. 9, 1909. (Gift of Civic League of San Francisco.)

Experimenta Nova (ut vocantur Magdeburgica de Vacuo Spatio By Ottonis de Guericke. Amstelodami, 1672 (Reprinted at Leipzig, 1881.) (Gift of Edward Caldwell.)

Foreign Trade Merchant Marine of the United States:—Can it be Revived? By G. W. Dickie. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Incidental Problems in Gas Producer Tests. (Bulletin no. 393, U. S. Geological Survey). By R. H. Fernald and others. Washington, U. S. Government, 1909. (Gift.)

Influence of the Position of the Midship Section upon the Resistance of Some Forms of Vessels. By H. C. Sadler. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Institution of Electrical Engineers. List of Officers and Members, corrected to Aug. 31, 1909. London, 1909. (Exchange.)

Insurance Society of New York. Bulletin, Vol. 1, no. 4, October, 1909. New York, 1909. (Gift.)

Jurisdiction and Work Public Service Commission, First District. n. p., n. d. (Gift of New York State Public Service Commission, First District.)

Lavorazione e Tempera Degli Acciai. By A. Massenz. Milano, U. Hoepli, 1909. (Gift of publisher.) Price, 2 lires.

Makers of Electricity. By Brother Potamian and J. J. Walsh. New York, 1909. (Gift of Brother Potamian.)

Mercury Meter Case. General Electric Company, *vs.* Sangamo Electric Company. Opinion filed in the U. S. Circuit Court of Appeals. Oct. 5, 1909. (Gift.)

National Association of Cement Users. Proceedings of Fifth Annual Convention. n. p., 1909. (Gift.)

National Fire Protection Association. Officers and Committees 1909–1910, Membership Directory, September, 1909. Boston, 1909. (Exchange.)

Nonpareil Corkboard Insulation. Pittsburgh, 1909. (Gift of Armstrong Cork Company.)

Peabody College for Teachers. Memorial Addresses. Nashville, 1909. (Gift.)

Preliminary Abstracts of Reports for the year ended December 31, 1908 of the Edison Electric Illuminating Company of Brooklyn, Lessee, Amsterdam Electric Light, Heat and Power Company, Kings County Electric Light and Power Company, Flatbush Gas Company (electric operations), New York and Queens Electric Light and Power Company, Richmond Light and Railroad Company, Bowery Bay Electric Light and Power Company, Bronx Gas and Electric Company and Queens Borough Gas and Electric Company (Exchange public Service Commission for the First District.)

Prevention of Industrial Accidents. No. 1, General. New York, 1909. (Gift of Fidelity and Casualty Company of New York.)

Producer Gas Boat Marenging. By H. L. Aldrich. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Recherches Théoriques et Expérimentales sur l'Electricité. By Mary Davy. Paris, 1861. (Gift of W. D. Weaver.)

Report of the Committee on Supervision of Public Improvements and Expenditures of the Civic League of San Francisco. Sept. 30, 1909. n. p. n. d. (Gift of Civic League of San Francisco.)

Report on Electrolysis. By W. S. Williams to the Committee on Supervision of Public Improvements and Expenditures Civic League of San Francisco, Oct. 1909. n. p. n. d. (Gift of Civic League of San Francisco.)

Results of Observations made at the Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland, 1905 and 1906. By D. L. Hazard. Washington, U. S. Government, 1909. (Gift.)

Rivets in Tension. By R. Curr. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Selden Automobile Patent Cases. Opinion of His Honor Judge Hough, filed Sept. 15, 1909. Sustaining the Selden Patent and Holding it Valid and Infringed. n. p. n. d. (Gift of Association of Licensed Automobile Manufacturers.)

Some Ship-Shaped Steam Forms. By W. McEntee. (Society of Naval Architects and Marine Engineers, Nov. 1909.) (Gift.)

Submarine Signal Bulletin nos. 33–35. Boston, 1909. (Gift of Submarine Signal Company.)

Submarine Signalling. Boston, 1909. (Gift of Submarine Signal Company.)

Submarine Signals. Boston, 1908. (Gift of Submarine Signal Company.)

Submarine Sound Signals. (Reprint of Hydrographie Information, no. 5, June 30, 1909.) Washington, 1909. (Gift of Submarine Signal Company.)

Summary of Compulsory Attendance and Child Labor Laws. n. p. n. d. (Gift State of New York Education Department.)

Summary of Quarterly Reports of Railroads and Street Railways Operating in the City of New York for April–June, 1909. New York, 1909. (Gift of New York State Public Service Commission, First District.)

U. S. Weather Bureau. Report of the Chief. 1901–1907, Washington, U. S. Government, 1902–1908. Exchange U. S. Weather Bureau.

Vermont Engineer. Annual publication of the Association of Vermont Engineers. Volume 1, 1909. Burlington, 1909. (Gift.)

Western Union Telegraph Company. Annual Report of the President to the Stockholders, Oct. 13, 1909. New York, 1909. (Gift.)

Lo Zinco. By R. Musu-Boy. Milano, U. Hoepli, 1909. (Gift of publishers.) Price, 3.50 lires.

GIFT OF THE ALUMINUM COMPANY OF AMERICA

Alloys of Aluminum, 1909.
Fabricated Aluminum, 1909.
Methods of Working Aluminum, 1909.
Properties of Aluminum, 1909.
Useful Tables, 1909.

GIFT OF EDWARD CALDWELL

Electrical Doings. Vol. 1, no. 3, June, 1896.

Electrical and Street Railway Reporter. Vol. 1, no. 1, March, 1894.

Inventive World. Vol. 1, no. 1, July, 1894.

Magnet. Vol. 1, no. 1, Feb. 14, 1880.

Mechanical and Electrical Progress. Vol. 1, no. 6, Oct. 1891.

New York Electrical Society. Electric Railway Operation in a Great City. By H. H. Vreeland, 1905.

Street Railway News. Vol. 1, no. 9, Sept 5, 1891.

Telephone World. Vol. 1, nos. 1, 3, 4; Vol. 2, nos. 1, 2, 4, 5, Lafayette, 1906.

TRADE CATALOGUES

American La France Fire Engine Co., Elmira, N. Y. Catalogue of Chemical fire apparatus and steam fire engines. 39 pages.

George E. Benz & Co., St. Louis, Mo. Catalog No. 200 of ribbon, metal, and celluloid badges; buttons, banners, flags, regalia, etc., 24 pp.

Bruce-Macbeth Engine Co., Cleveland, O. Catalogue of "Meriam" vertical gas engines for electric lighting, pumping, and general power purposes. 31 pp.

Electric Controller & Supply Co., Cleveland, O. January issue of "Common Sense," a magazine published in the interest of lifting magnets.

Electric Storage Battery Co., Phila, Pa. Catalogue section A, 1908, on types of the "Chloride Accumulator" for electric railway service, central lighting and power stations, isolated lighting and power plants, etc. 22 pp.

——Catalogue section B on sundry parts and supplied for use in connection with batteries manufactured by Electric Storage Battery Co. 24 pp.

——Catalogue C on car lighting cells: "Chloride Accumulator," and "Tudor Accumulator." 42 pp.

——Handbook I P on the "Chloride Accumulator" in small isolated lighting plants. 16 pp.

——Handbook L. V. on the "Chloride Accumulator" for low voltage isolated lighting plants with Tungsten lamps. 10 pp.

——Catalogue P on the chloride accumulator and the "Exide" battery in portable form. 9 pp.

——Catalogue S on the "Exide" battery and the chloride accumulator for ignition service for automobiles, motor boats, and stationary gas and gasoline engines. 12 pp.

——Catalogue X on the "Exide" battery and the "Hycap-Exide" battery for electric vehicles. 16 pp.

——Catalogue on the "Exide" sparking battery. 31 pp.

——A sketch of the development of the "Exide" and "Hygap-Exide" batteries. 24 pp.

——Pamphlet on the subject: "How to get more speed and more power out of your car. 8 pp.

——The "Exide" sparking battery instruction book. 16 pp.

——Instructions for the care of the "Exide" battery in electric vehicles. 36 pp.

——General instructions for installing and operating the "Chloride Accumulator and the "Tudor Accumulator" in car lighting service. 61 pp.

——Circular No. 47. The installation of chloride accumulators in the sub-stations of the South-Side Elevated Railroad Co. of Chicago. 6 pp.

——Bulletin No. 67. The operation of the "Chloride Accumulator" by the Brooklyn Heights Railroad Co. 6 pp.

——Bulletin No. 69. The distribution of electrical energy in large cities. L. A. Ferguson. 9 pp.

——Bulletin No. 75. The installation of "Chloride Accumulators" for the electric lighting of railway cars. 4 pp.

——Bulletin No. 77. The installation of "Chloride Accumulators" at the Alum Rock station for the San Jose & Santa Clara Railway Co. 4 pp.

——Bulletin No. 80. The installation of chloride accumulators for the Ottawa Electric Railway Co. 6 pp

——Bulletin No. 81. The installation of chloride accumulators for the San Francisco, Oakland, & San Jose Railway Co. 3 pp.

——Bulletin No. 83. The operation of chloride accumulators in connection with the exciter circuits of large alternating current generating stations. 4 pp.

——Bulletin No. 87. The automatic water-filling apparatus and compensating hydrometer for use with chloride accumulator. 4 pp.

——Bulletin No. 88. The installation of chloride accumulators for the Edison Electric Co. of Los Angeles, California. 4 pp.

——Bulletin No. 89. Installations of chloride accumulators in small central lighting and power stations. 4 pp.

——Bulletin No. 91. The chloride accumulator in the electrification of steam railroads. 6 pp.

——Bulletin No. 92. The two-plate type of the chloride accumulator. 3 pp.

——Bulletin No. 93. The carbon regulator for automatic booster control. 4 pp.

——Bulletin No. 95. The installation of chloride accumulators for the Carnegie Steel Co. at Youngstown, Ohio. 6 pp.

——Bulletin No. 96. Chloride accumulators in residential lighting and power plants. 4 pp.

——Bulletin No. 97. The chloride accumulator in railway and central lighting station service in the cities of Milwaukee and Chicago. 6 pp.

——Bulletin No. 98. The chloride accumulator in central station lighting and power plants. 9 pp.

——Bulletin No. 99. The chloride accumulator for the operation of electric signals and interlocking switches. 3 pp.

——Bulletin No. 100. The chloride accumulator for electric lighting of railway cars. 5 pp.

——Bulletin No. 101. The installation of chloride accumulators for the Columbus Railway and Light Co. 5 pp.

——Bulletin No. 102. High speed magnetic control end cell switch for use with chloride accumulators for Edison and Exciter service. 2 pp.

——Bulletin No. 103. The chloride accumulator in telephone service. 10 pp.

——Bulletin No. 104. The chloride accumulator in small isolated lighting and power plants. 3 pp.

——Bulletin No. 105. The chloride accumulator in small central station lighting and power plants. 4 pp.

——Bulletin No. 106. The chloride accumulator for alternating current regulation. 3 pp.

——Bulletin No. 107. The chloride accumulator as applied to the single phase system of the Spokane and Inland Railway. 2 pp.

——Bulletin No. 108. The chloride accumulator installed for the Lukens Iron and Steel Works, Coatesville, Pa. 4 pp.

——Bulletin No. 109. The sale of current for electric automobiles by electric lighting and power stations. 11 pp.

——Bulletin No. 110. The operation of chloride accumulators in connection with remote control oil switches. 2 pp.

——Bulletin No. 112. The chloride accumulator in iron and steel mills. 8 pp.

——Bulletin No. 113. The use of the chloride accumulator with electrically operated drawbridges. 2 pp.

——Bulletin No. 114. The " Exide " battery and the " Hygap-Exide " battery for electric vehicles. 9 pp.

——Bulletin No. 115. The chloride accumulator as installed in the Hudson Terminal Building, New York. 3 pp.

——Bulletin No. 116. Some points on the operation and care of " Exide " vehicle batteries. 7 pp.

Emerson Electric Mfg. Co., St. Louis, Mo. Bulletin No. 3137. Single phase induction motors, 1/15 to 1/5 horse power. 4 pp.

——Bulletin No. 3308. Blowers for hot-air furnaces for residence use. 7 pp.

——Bulletin No. 3309. Electric forge blowers direct-connected for direct and alternating currents. 7 pp.

General Electric Co., Schenectady, N. Y. Advance announcement of articles to appear in General Electric Review for November, 1909. 3 pp.

——Price list No. 5210 of G. E. standard Tungsten incandescent lamps and high efficiency holophanes. 6 pp.

——Bulletin No. 4691. Small polyphase motors. 8 pp.

——Bulletin No. 4694. Portable substations for electric railways. 8 pp.

——Bulletin No. 4695. G. I. type K enclosed arc lamps. 16 pp.

——Bulletin No. 4698. Luminous arc headlights. 6 pp.

——Bulletin No. 4699. Motor driven air compressors, geared type. (2 copies.) 6 pp.

——Bulletin No. 4700. General Electric Switchboard instruments, type R2. 5 pp.

——Bulletin No. 4701. Emergency straight air brake system. 10 pp.

——Bulletin No. 4704. G. E., 219 railway motor. 15 pp.

General Electric Co., Schenectady, N Y. Folders on

——Tricoat wires and cables, N. E. Code thickness of insulation.

——Supply Catalogue No. 7586 on Repair parts of C. B.-15-G railway motor, giving catalogue number, descriptive title, and prices of various parts.

——Bulletin on Panel boards and cabinets, giving cuts, forms, styles, dimensions, and prices.

——Bulletin No 4676, August, 1909. Multiple enclosed arc lamp for factory, office, store, armory use, and articles describing its construction, advantages, and efficiency.

——Bulletin No. 4690, August, 1909. Type MA fuse boxes, with description of construction, and diagram of dimensions.

——Bulletin No. 4692, September, 1909. G. E. 210 railway motor, with illustrations and articles on detail construction, rating, schedule speed chart, and dimension diagram.

Gesellschaft für drahtlose Telegraphie, Berlin, Pamphlets on Wireless telegraph outfits.

——Receiving apparatus, giving cuts and description of apparatus, as well as instructions to operator.

——Leyden jars, used in connection with the wireless " Telefunken " system.

——Spark gaps, showing construction, wiring, and instructions for operating.

——Induction coils with illustrations and description of construction.

Hersey Manufacturing Co., South Boston, Mass. Detector-meters for fire services. 12 pp.

Otis Elevator Co., Yonkers, N. Y. The Indicator, June and September, 1909, published in the interest of the Otis Elevator Industry.

——Special " National Electric Light Association," convention edition of the Indicator, June, 1909. 12 pp.

Peerboom & Schurmann, Düsseldorf, Germany. Price list and catalogue of tachometers, and tachographs, instruments which register without the assistance of a watch the number of revolutions per minute of steam engines, turbines, pumps, centrifugal appliances, and electrical machinery.

Scully Steel & Iron Co., Chicago, Ill. October, 1909 stock list of iron and steel supplies carried by the Scully Co. 96 pp.

Sturtevant Mill Co., Boston, Mass. Plate steel crushers for coarse, intermediate and fine crushing. 14 pp.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa. Long scale indicating instruments for alternating-currents, as armatures, voltmeters, and wattmeters.

——Discount sheet and new sections for catalogue No. 1001.

Catalogue sections on, Distributing transformers.

——Type C overload and reverse current relays.

——Protective apparatus for street railway service.

——Single catenary trolley line material.

——Electric irons.

——Sealing tools and seals.

——Style Number Index.

——Type E oil circuit breakers.

——Type GA oil circuit breakers.

——Synchronoscopes.

——Shunts for D.C. Ammeters.

——Portable meters.

UNITED ENGINEERING SOCIETY

Engineers' Club of Cincinnati. Secretary's Report and List of Members, Cincinnati, 1890–1905, 1907–1909.

OFFICERS AND BOARD OF DIRECTORS, 1909-1910

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(Term expires July 31, 1910.)
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HENRY GORDON STOTT.
LOUIS A. FERGUSON.

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(Term expires July 31, 1910.)	(Term expires July 31, 1911.)
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CALVERT TOWNLEY.	PAUL SPENCER.

MANAGERS.

(Term expires July 31, 1910.)	(Term expires July 31, 1911)	(Term expires July 31, 1912.)
MORGAN BROOKS.	DAVID B. RUSHMORE.	A. W. BERRESFORD.
HAROLD W. BUCK.	W. G. CARLTON.	WILLIAM S. MURRAY.
PERCY H. THOMAS.	CHARLES W. STONE.	HENRY H. NORRIS.
BENJAMIN G. LAMME.	H. E. CLIFFORD.	SEVERN D. SPRONG.

(Term expires July 31, 1910.)

TREASURER.

GEORGE A. HAMILTON.
Elizabeth, N. J.

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33 West 39th Street, New York.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

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*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.]
A. E. KENNELLY, 1898-1900
CARL HERING, 1900-01.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY GORDON STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-9.

*Deceased.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York.

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HENRY G. STOTT, New York, N. Y.
SAMUEL SHELDON, Brooklyn, N. Y.
LOUIS A. FERGUSON, Chicago, Ill.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY

SAMUEL SHELDON, Brooklyn, N. Y.
HENRY G. STOTT, New York.
LOUIS A. FERGUSON, Chicago, Ill.

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SAMUEL SHELDON, Brooklyn, N. Y.

ON GOVERNMENT ADVISORY BOARD ON FUELS AND STRUCTURAL MATERIALS

FRANCIS B. CROCKER, New York.
HENRY G. STOTT, New York.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

SAMUEL SHELDON, Brooklyn, N. Y
PERCY H. THOMAS. New York

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NOTE

The following paper is to be read at the regular meeting of the American Institute of Electrical Engineers in **New York City, December 16, 1909.** This meeting is to be held under the auspices of the High-Tension Transmission Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

In contributing to a discussion, whether orally or in writing, it is requested that the matter under discussion be taken up in the order followed in the paper, and that, after having dealt with the matter of the paper, there be introduced any other matter which the contributor may deem desirable.

Written contributions will be read at the meeting for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper so far in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman High-Tension Transmission Committee, 60 Wall Street, New York,** so that they will be received not later than December 13, 1909.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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THE CONVECTION OF HEAT FROM SMALL COPPER WIRES

BY A. E. KENNELLY, C. A. WRIGHT AND J. S. VAN BYLEVELT

It is well known that when an electrically heated wire is supported in air, it dissipates its heat by conduction, radiation and convection.

Conduction takes place longitudinally through and into the metallic terminals of the wire, and would take place laterally through the air, if the latter were kept at rest like a rigid medium. The metallic conduction at the ends may be eliminated by confining observation to parts of the wire not near the ends. The lateral conduction through the air is also negligible, because the air does not remain at rest but expands and flows convectively. Consequently we may safely ignore conductive thermal loss.

Radiation loss from the wire is a function of the surface area of the wire, its temperature, the nature of its physical surface, and the temperature of surrounding substances. For a given wire with a given surface condition and in a given environment, radiation loss is regarded as a function of temperature only.

Convection loss from the wire is a hydrodynamic phenomenon, involving the flow of air past the surface of the wire, and the amount of heat which this moving stream of air can carry off. Very little seems to be known quantitatively about convection. It is the object of this paper to describe a research made on the convective loss of heat from small copper wires, of less than 0.7 mm. or 27.5 mils diameter, and to present some quantitative results arrived at from the observations.

In order to study convection loss to advantage, it is desirable to experiment on small wires; because, for a given temperature elevation of the wire, the radiation increases in proportion to the surface area; whereas the free convection is independent of the surface area, to a first approximation. Consequently, a wire of small surface area per unit of length, *i.e.*, a thin wire, will have relatively small radiation loss by comparison with its convective loss. On the other hand, when radiation loss is the subject of investigation, it is desirable to employ conductors of large surface per unit of length.

We may divide convection into two classes:

1. Free convection, when the wire is supported in free still air; that is, air substantially free from draughts, or movements, except such as may be produced by the heated wire alone.

2. Forced convection, when the wire is in motion relatively to the surrounding air; that is, when the wire is either moved bodily through the air, or is held in a stream of moving air.

An electrically heated wire is therefore subject to free convection when it is supported at rest in still air, substantially free from draughts or wind motion. It is subject to forced convection when it is either moved bodily through the air, or when it is placed in a wind.

In order to separate convection loss from radiation loss, it is desirable to operate the wire under test at constant temperature and at a constant temperature elevation above surrounding solid bodies. The radiation loss will then be constant, and changes in the surrounding air will give rise to changes in heat dissipation that may safely be attributed to changes in convection alone.

The experimental methods employed in this research were:

1. To vary the atmospheric pressure surrounding the test wire, under conditions of free convection, and to measure the change of electric power required to maintain the wire at constant temperature elevation.

2. To subject a wire to varying wind velocity, under conditions of forced convection, and to measure the change of electric power required to maintain the wire at constant temperature elevation.

FREE CONVECTION AT VARYING ATMOSPHERIC PRESSURE

General plan. A short length of the copper wire under test was supported horizontally* in an air-tight tank and supplied with a steady current from a storage battery. By adjusting the current strength, the wire was kept at constant resistance, and, therefore, at constant temperature. The pressure of air in the tank was varied by means of an air-pump.

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* It has been found that, other things being the same, a wire supported in a vertical position becomes slightly hotter than when supported horizontally, apparently owing to the action of the enveloping stream of convectively heated air.

Copper wires. Three sizes of small, bare, soft commercial copper wire were employed, the particulars of which appear in the following table.

Electrical connections in free convection tests. The connections employed are illustrated in Fig. 1. A storage battery E, of from 4 to 16 volts, supplied current to the main circuit R^1, R, A, h. The resistance h was an adjustable carbon rheostat. The current strength was measured on a standard laboratory ammeter A, the scale of which had recently been calibrated. The resistance R is that of the length of the test wire supported horizontally inside the pressure tank $B\,C\,D\,F$. The constant resistance R^1 was of German-silver wire, selected as approximately equal to the resistance of the test wire R. Pressure wires were taken both from the constant resistance R^1 and the test wire R to the coils G^1 G of a differential galvanometer. If G and G^1 are the respective resistances of the galvanometer coils, we have at any differential balance:

TABLE I
PARTICULARS OF COPPER WIRES USED IN FREE CONVECTION TESTS

Test-wire No.	Diameter		Cross-sectional area	Surface per linear cm.	Length of wire under test	Resistance of wire @ 20° cent.	Resistance of wire @ 0° cent.	Linear resistance @ 0° cent	Resistivity @ 0° cent.
	Cm.	Inches	sq. cm.	sq. cm.	cm.	absohms	absohms	abs-ohms/cm.	abs-ohm-cm.
1	0.01143	0.0045	1.026×10^{-4}	0.03591	30.88	0.5133×10^{9}	0.4736×10^{9}	153.4×10^{5}	1574
2	0.02616	0.0103	5.374 "	0.08219	118.6	0.3784 "	0.3491 "	29.44 "	1582
3	0.06907	0.0272	37.47 "	0.217	102.5	0.0467 "	0.04308 "	4.203 "	1575

$$\frac{R}{R^1} = \frac{G+\rho}{G^1} \qquad \text{numeric} \qquad (1)$$

where ρ is an adjustable resistance capable of being inserted in either galvanometer circuit.

Method of measuring. The resistance of the test wire having been determined carefully with a feeble measuring current, a temperature elevation was determined on for the test wire. To this temperature elevation corresponded a test-wire resistance:

$$R_T = R_0\,(1+0.0042\,T) \qquad \text{absohms† or c.g.s. mag. units of resistance.} \qquad (2)$$

Where R_T is the resistance of the test wire at the working temperature T degrees cent., R_0 its resistance at 0 degrees cent., and 0.0042 the assumed temperature coefficient of resistivity for copper* used throughout this research. If the temperature of the air in the tank was t degrees cent., the temperature elevation of the test-wire was $\theta = (T - t)$ degrees cent. The correct value of ρ in Fig. 1 was taken from equation (1), to give differential balance at R_T; so that as long as the galvanometer indicated that balance was maintained, it was evident that the temperature elevation $T - t = \theta$, of the test-wire, was constant. The current strength in the main circuit $E\,R^1\,R\,A\,h$ was then kept at such a value, by adjustment of h, that the differential balance was maintained. This current strength was measured on the ammeter A, as the air-pressure in the tank was changed. The apparatus used is illustrated in Fig. 12, from a photograph.

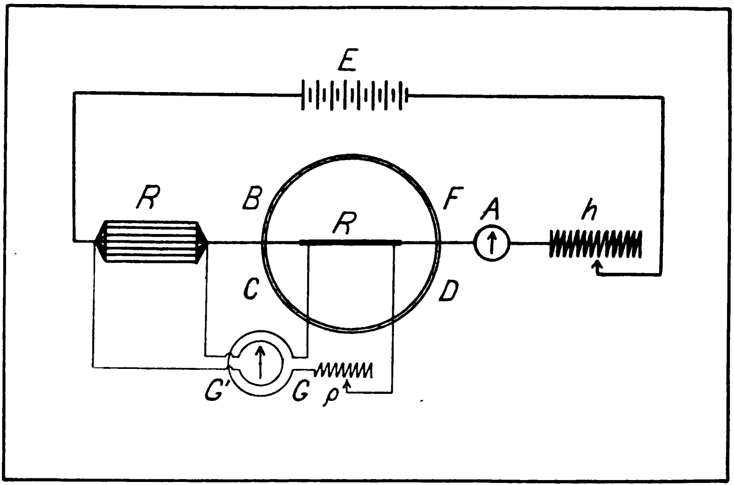

FIG. 1.—Electrical connections in measurements of free convection.

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† An absohm is the c.g.s. magnetic circuit of resistance. See TRANSACTIONS, A.I.E.E., Vol. XXII, p. 534.

* Standardization Rules of the Am. Inst. of El. Engrs: Third Edition, 1908, p. 32, Sec. 360.

The galvanometer. The galvanometer used was of the Edelmann type, in which a suspended ring magnet swings in a copper cylinder, so as to secure suitable electromagnetic damping. The resistance of each of the windings *G G′*, Fig. 1, was in the neighborhood of 1800 ohms. At the distance of 140 cm. between scale and mirror, 1 mm. deflection was produced by approximately 0.14 microampere. The periodic time of the galvanometer was about five seconds. The damping ratio of successive opposite elongations was 2.55; or the Naperian logarithmic decrement of successive opposite elongations was 0.9361. Four complete swings, executed in 20 seconds, sufficed to reduce the deflection to 1/1790 part, or, for practical purposes, to rest. The galvanometer was read by a telescope and scale, and in nearly all of the work it was used as a zero instrument. The resistance of each coil was measured after each test. The differential balance was also checked, and, if necessary, adjusted before each test.

The German-silver constant resistances. The German-silver resistances *R′*, Fig. 1, were made up of grids of German-silver wire, so as not to heat appreciably with the strongest testing current used. Two such resistances were employed in different series of tests, one of 0.4248 ohm at 18 degrees cent., and the other of 0.04572 ohm at 18 degrees cent., between pressure wires. The working current values employed were ordinarily such as to produce from 0.4 to 2.0 volts potential difference between the pressure wires of these resistances.

The pressure-tank, or cylinder. The pressure tank, inside which the test wire was supported, was a vertical cylinder of the form indicated in Fig. 2, constructed of ½-in. (1¼ cm.) steel plates riveted. Its internal diameter was 60 inches (152 cm.) and its height 21.8 ft. (6.66 meters), the ends being rounded off hemispherically. The test wire was supported horizontally, about 4.36 feet (1.33 meter) from the bottom of the cylinder. A steam-driven air pump, in an adjoining room, was connected to the bottom of the cylinder, so that air could be pumped either into or out of the latter. Access to the interior of the cylinder was obtainable through two manholes, one of which enabled the wires to be admitted through an air-tight gland.

The atmospheric pressure in the cylinder was measured by means of a glass U-tube manometer containing distilled mercury, one leg of this tube being connected to the cylinder and the other left open to the outside air. The pressure in the tank at any time

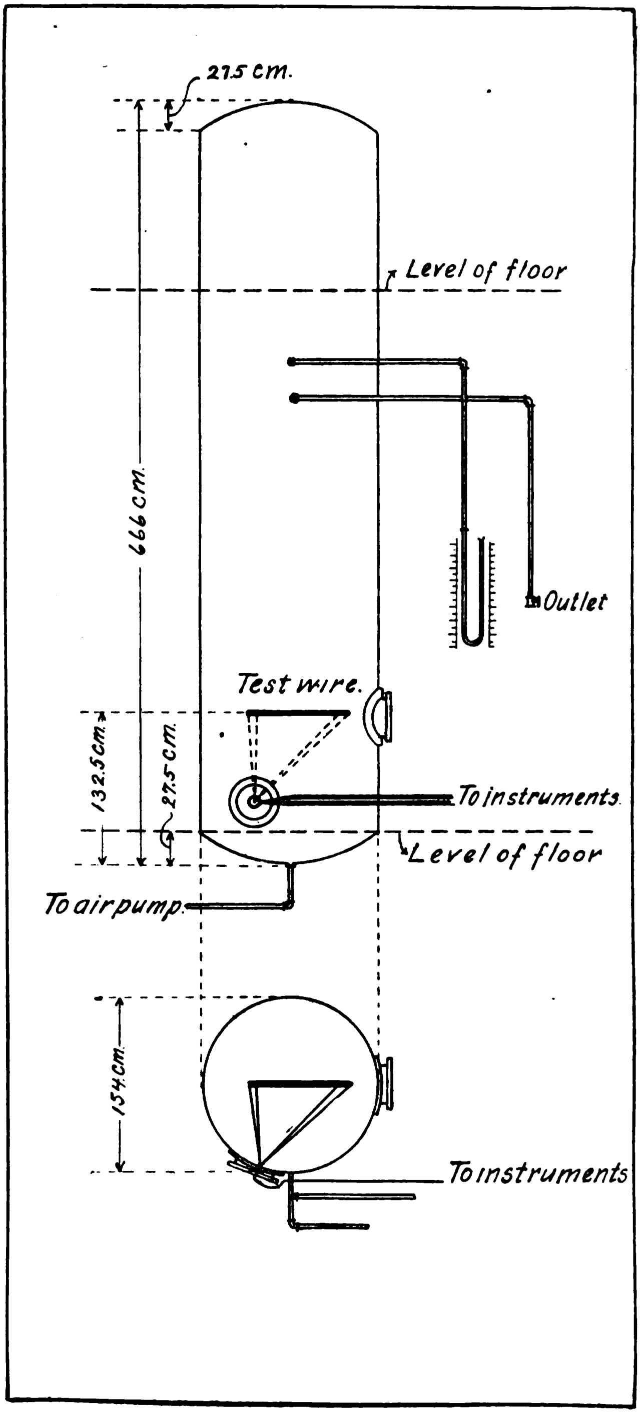

FIG 2.—Plan and elevation of tank

was taken as equal to the barometer reading in the open air, plus the difference of level in the U-tube.

Specimen series of measurements. The following table gives a specimen series of measurements made on test-wire No. 2 with ρ = 100 ohms in the circuit of galvanometer coil G, and the copper wire R:—

TABLE II

SAMPLE SERIES OF OBSERVATIONS IN FREE CONVECTION TEST

I Air pressure. cm.	II Air pressure. megabars	III I absamp.	IV I^2 absamp.^{2}	V $P = I^2 r_T$ Linear power. abwatts /cm.	VI P_r Linear radiation. abwatts /cm.	VII P_c Linear convections. abwatts /cm.	VIII P_c/θ Linear convection per degree cent. elevation
		$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^5$	$\times 10^5$	$\times 10^5$	$\times 10^3$
28.8	0.3821	2.84	0.8066	3.182	0.321	2.861	4.87
30.4	0.4030	2.83	0.8009	3.160		2.839	4.83
40.45	0.5365	2.909	0.8462	3.340		3.019	5.14
48.35	0.6420	2.979	0.8874	3.502		3.181	5.42
57.61	0.765	3.060	0.9364	3.694		3.373	5.73
65.15	0.864	3.083	0.9505	3.750		3.429	5.84
65.2	0.866	3.083	0.9505	3.750		3.429	5.84
72.8	0.961	3.10	0.9610	3.792		3.471	5.91
72.85	0.966	3.10	0.9610	3.792		3.471	5.91
165.0	2.193	3.42	1.1696	4.614		4.293	7.31
155.2	2.06	3.36	1.1290	4.454		4.133	7.04
143.8	1.908	3.299	1.0883	4.294		3.973	6.76
143.5	1.907	3.30	1.0890	4.297		3.976	6.77
141.7	1.882	3.375	1.1391	4.494		4.173	7.11
128.9	1.712	3.334	1.1115	4.387		4.066	6.94
116.15	1.542	3.32	1.1022	4.348		4.027	6.85
116.2	1.543	3.318	1.1009	4.344		4.023	6.85
101.5	1.349	3.20	1.0240	4.040		3.719	6.33
101.1	1.344	3.198	1.0227	4.037		3.716	6.33
101.1	1.344	3.194	1.0202	4.024		3.703	6.30
92.75	1.231	3.139	0.9853	3.887		3.566	6.07
92.6	1.229	3.181	1.0119	3.951		3.630	6.30
75.55	1.003	3.092	0.9560	3.772		3.451	5.86
75.6	1.003	3.10	0.9610	3.792		3.471	5.90
75.6	1.003	3.118	0.9722	3.835		3.514	5.98

G = 1805 ohms, G' = 1729 ohms.

R' = 0.4248 ohms, R = 0.4681 ohms.

Temperature of tank t = 18.1 degrees cent. = 291 degrees absolute.

Temperature of wire $T = (t+\theta)$ = 76.9 degrees cent. = 349.9 degrees absolute.

Temperature elevation of wire θ = 58.8 degrees cent.

Linear resistance of wire at working temperature 3.946×10^6 absohms per cm.

Barometer 29.78 in. (75.64 cm.) at 19 degrees cent.

Column I gives the pressure of the air in the tank in cms. of mercury. Column II gives the pressure in megabars. In Column III, the current strength is given in absamperes. In column IV appears the absamperes squared. Column V shows linear power dissipated as $P = I^2 r_T$ in abwatts per cm. The linear radiation appears in Column VI. Subtracting the linear radiation from the linear power, we obtain the linear convection in abwatts per cm. The last column gives the last-named result divided by the temperature elevation, or the linear convection per degree centigrade of temperature elevation.

Air-pressures in absolute measure. In Column II of the foregoing table, the air-pressure in the tank is recorded in megabars.* The c.g.s. unit of pressure, 1 dyne per sq. cm. has been called the " bar "; so that a megabar is 10^6 dynes per sq. cm. According to the recently published data of the Bureau International des Poids et Mesures,† a column of mercury 760 mm. (29.92 in.) high, at sea level, in latitude 45 degrees, exerts a pressure of 1.0132 megabars. Consequently 1 megabar represents the pressure of a column of mercury of 750.09 mm. (29.53 in.) under the same conditions. For most practical purposes, therefore, a megabar may be taken as 1 atmosphere. It is actually 0.987 of an atmosphere of 760 mm., at sea level and 45 degrees latitude.

Allowance for linear radiation. The accepted formula for superficial power P_r radiated from a metallic cylindrical surface at a temperature of T_a degrees absolute to surrounding solid substances at a temperature of t_a degrees absolute, is called Stefan's formula:

$$P_r = \sigma (T_a^4 - t_a^4) \qquad \text{abwatts per sq. cm.} \qquad (3)$$

where σ is Stefan's coefficient, which depends upon the surface condition of the radiator. For a " black " body, or a body that emits heat by radiation to the full maximum without any reflection of incident heat, the value of σ has been found by Lummer and Kurlbaum to be 5.3×10^{-5} abwatts per sq. cm. and per degree absolute. On the other hand, a colored body or non-black body, which reflects some radiation and therefore radiates imperfectly, has a smaller Stefan coefficient, which it is necessary to determine experimentally in each case.

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* Richards and Stull. Dec. 1903. New Method for Determining Compressibility. *Carnegie Institution Publ.* No. 7, p. 43.

† Les Récents Progrès du Système Métrique. 1907, pp. 30-31.

In the tests published by one of the writers, in 1889, on copper wires electrically heated in air, the conclusion was reached that, with an ordinary unpolished surface, the wires radiated 0.0786 watt per sq. cm. at 126 degrees cent. to surrounding bodies at 26 degrees cent. Substituting in equation (3), $T_a = 399$, $t_a = 299$ and $P_r = 7.86 \times 10^5$ abwatts per sq. cm., we obtain for bright copper wire $\sigma = 4.5 \times 10^{-5}$ abwatts per sq. cm. and degree absolute.

In allowing for the linear radiation from the wire used in this research, the value taken for σ is 5×10^{-5} abwatts per sq. cm. × degrees absolute. The accuracy of this choice is not of great importance in this case, because the radiation was always small with respect to the convection. Thus in the case presented in Table II, it will be seen that the computed linear radiation from the wire was 0.32×10^5 abwatts per cm. with the above accepted value of σ; whereas the total linear emission varied between 3.18×10^5 and 4.49×10^5 abwatts per cm. Consequently if the Stefan coefficient σ were reduced 50%, or the linear radiation to 0.16×10^5 abwatts per cm., the change thereby effected in the linear convection would be only about 4%. In the case of the larger wire No. 3, the corresponding error would be approximately doubled, and in the case of the smaller wire No. 1, it would be roughly halved. Consequently, if it should be found in future that the Stefan coefficient for such copper wires is materially less than 5×10^{-5} abwatts per sq. cm. and degree absolute, the results for convection arrived at in this paper will not be greatly affected.

If we denote by P the linear dissipation of the test-wire or the power dissipated per linear cm., by P_r the linear radiation, and by P_c the linear convection, we have

$$P = I^2 r_T \qquad \text{abwatts per cm.} \qquad (4)$$

where I is the heating current in absamperes, and r_T the linear resistance at the working temperature T, in absohms per cm.

$$P = P_r + P_c \qquad \text{abwatts per cm.} \qquad (5)$$

$$= o\,\sigma\,(T_a^4 - t_a^4) + P_c \qquad \text{abwatts per cm.} \qquad (6)$$

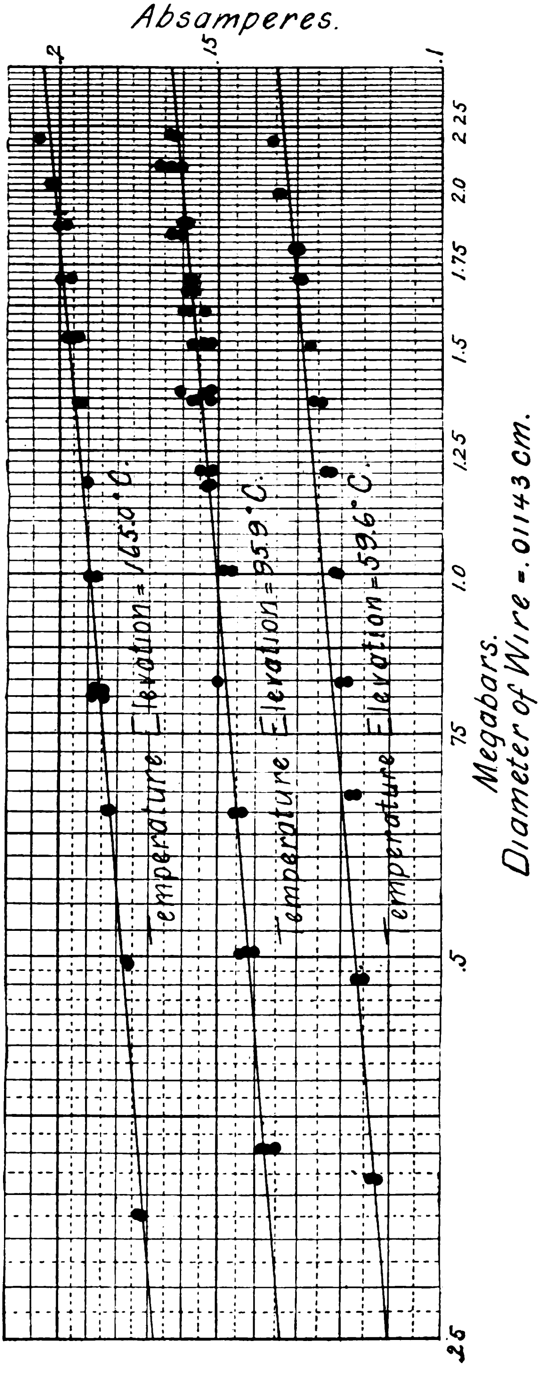

FIG. 3.—Current strengths for varying air-pressures

where o is the circumference of the wire or its surface per linear cm.

$$P_c = I^2 r_T - o\,\sigma\,(T_a^4 - t_a^4) \quad \text{abwatts per cm.} \qquad (7)$$

Results of measurements with free convection. At different times, thirteen series of observations were made on the dissipation of heat in the tank under varying atmospheric pressures, with the three test-wires specified in Table I. The results of these series are presented graphically in Fig. 3 for wire No. 1, in Fig. 4 for wire No. 2, and in Fig. 5 for wire No. 3. These figures are drawn on logarithmically scaled paper, with ordinates of current strength in absamperes through the test-wire, and abscissas of air-pressure in megabars within the tank. The temperature elevation of the wire θ, in degrees cent., is marked on each line. It will be seen that the observations conform fairly well to straight lines in each case, and that these lines are parallel for different temperature elevations on one and the same wire. This condition represents an equation of the form:

$$I_\theta = B_\theta\, p^m \qquad \text{absamperes} \qquad (8)$$

where B_θ is a constant for each series of observations, and I_θ is the current strength required to be kept flowing through the test wire in order to maintain its temperature elevation θ degrees cent., under an air pressure of p megabars. The tangent of the angle of inclination of the lines with the abscissa axis being equal to the exponent m, we find that for wire No. 1, $m = 0.09$; for wire No. 2, $m = 0.12$, and for wire No. 3, $m = 0.13$; so that the exponent varies with the diameter of the test wire.

In Fig. 6, the results for the three sizes of wire are collected and expressed to logarithmic scale, with ordinates showing linear convection in units of $10^5 \times$ abwatts per cm. and abcissas showing tank air-pressure in megabars. Again, the observations conform fairly well with straight lines, or indicate a relation:

$$P_c = A_\theta\, p^n \qquad \text{abwatts per cm.} \qquad (9)$$

where P_c is the linear convection, or power dissipated in convection per linear centimeter of the test wire, p is the tank air-pressure in megabars, A_θ is a constant for each wire at a given temperature elevation θ degrees cent., and n is an exponent equal to the tangent of the slope of the line. If there were no

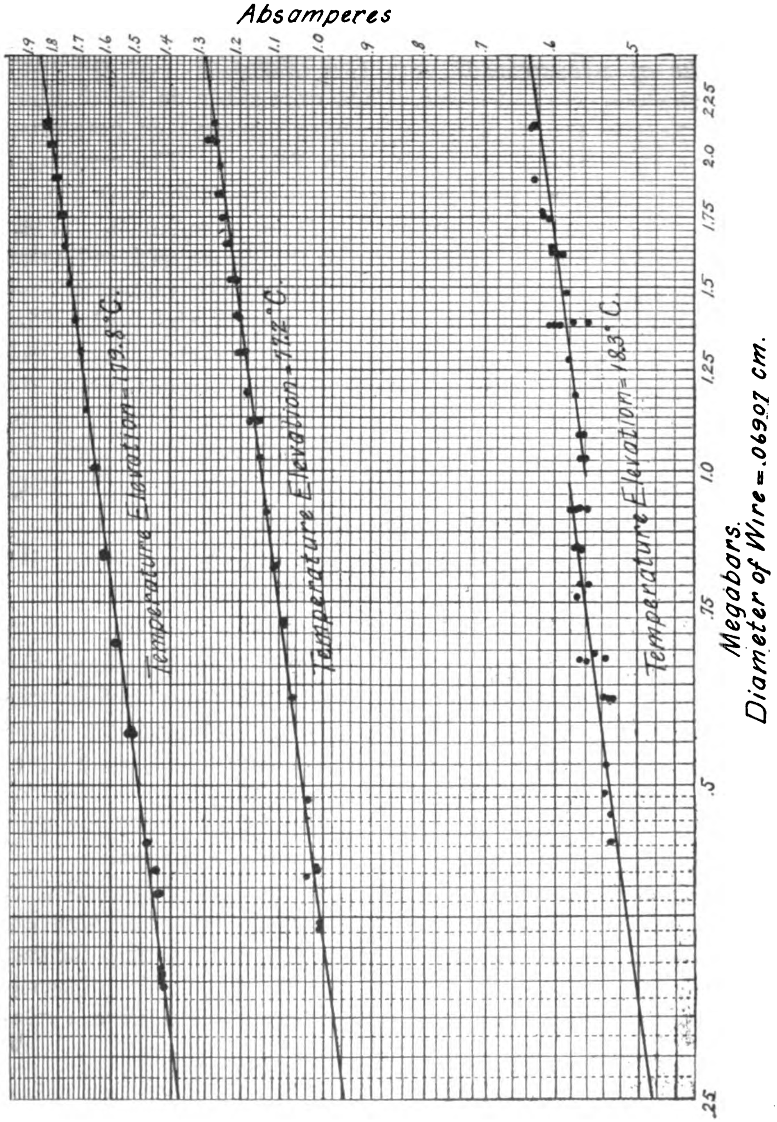

FIG. 4.—Current strengths for varying air-pressures

radiation to allow for, it would follow that $n = 2m$ for each wire, or the slopes in Fig. 6 would be respectively double those in Fig. 3, 4 and 5. We find, however, for wire No. 1, $n = 0.19$

for wire No. 2, $n = 0.268$, and for wire No. 3, $n = 0.38$, numerical values which approximately satisfy the relation:

$$n = 0.9 \sqrt[3]{d} \qquad \text{numeric} \quad (10)$$

where d is the diameter of the wire in cm.

If we analyze the values of A_θ in Fig. 6 for the standard air-pressure of 1 megabar (nearly 1 atmosphere), we obtain the results given in the following Table:

The foregoing table shows that we may express the linear convection for any one of these wires by the approximate formula:

$$P_c = c\,\theta\, p^{0.9\sqrt[3]{d}} \quad \text{abwatts per cm. and degree cent.} \quad (11)$$

TABLE III

LINEAR CONVECTIONS PER DEGREE CENT. TEMPERATURE ELEVATION AT THE AIR PRESSURE OF 1 MEGABAR

Diam. of wire cm.	Temp. elevation θ degree cent.	Linear convections at 1 megabar A_θ abwatts per cm.	Linear convection per degree cent. elevation at 1 megabar $c = A_\theta/\theta$	Mean c
0.01143	59.6	2.96×10^6	5,000	5,300
	95.9	4.95 “	5,200	
	165.	9.2 “	5,600	
0.02616	15.1	0.98 “	6,400	5,600
	37.8	1.8 “	4,800	
	46.4	2.45 “	5,300	
	46.8	2.47 “	5,300	
	58.8	3.58 “	6,100	
0.06907	18.3	1.4 “	7,800	8,500
	77.2	6.55 “	8,500	
	179.8	16.7 “	9,300	

where p is the air-pressure in megabars (between 0.15 and 2.5 megabars), d is the diameter of the copper wire in cm. (between 0.01 and 0.07 cm.), θ is the temperature elevation of the wire above ordinary room temperature, in degrees cent., (up to 180 cent.) and c is a quantity which is in the neighborhood of 6000 abwatts per cm. and per degree cent. at 1 megabar, and appears to increase slowly with the diameter of the wire, perhaps in a linear relation:

$$c = a + b\,d \qquad \text{abwatts per cm. and per degree cent., at 1 megabar.} \quad (12)$$

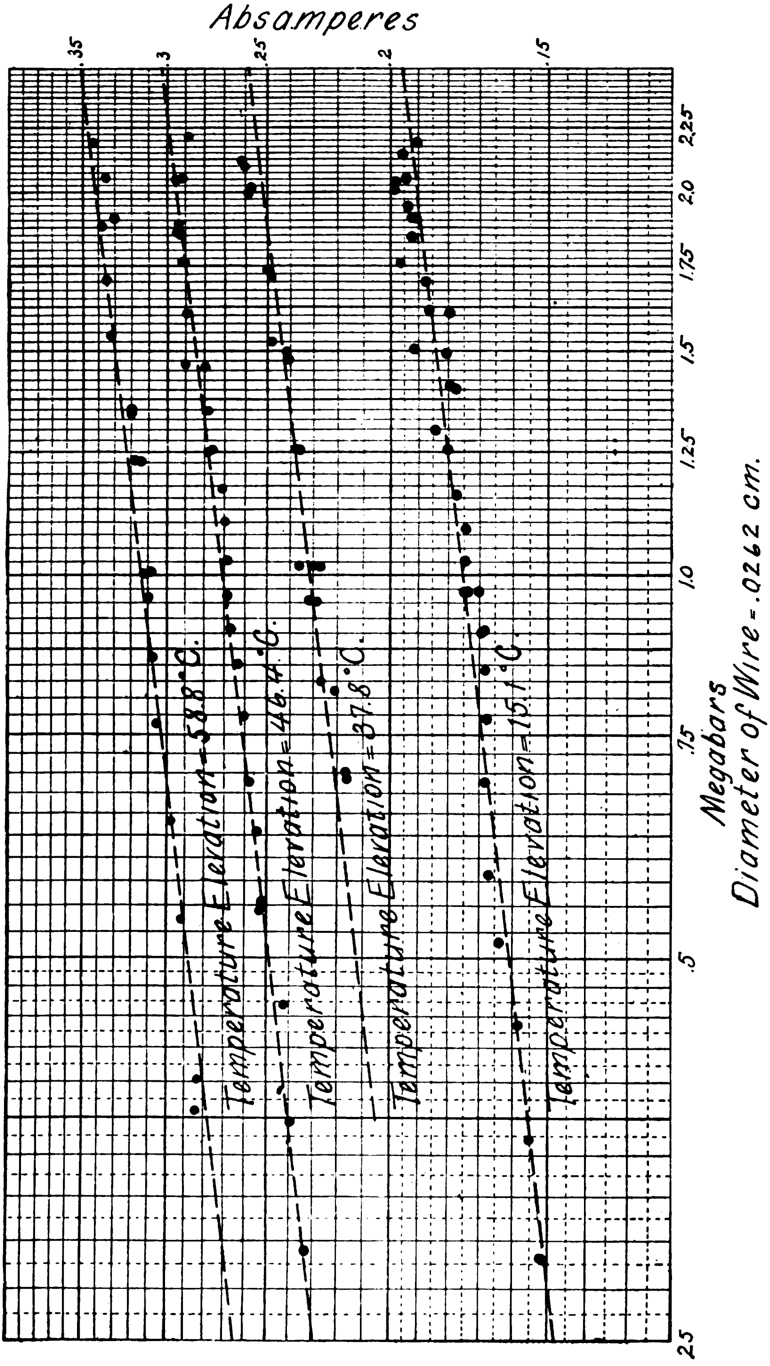

FIG. 5.—Current strengths for varying air-pressures

As a first approximation we might take:—

$$c = (4 + 64\,d)\,10^3 \qquad \text{abwatts per cm. and per degree cent., at 1 megabar.} \tag{13}$$

where d is the diameter of the wire in cm.

It is difficult to measure linear free convection from a wire with precision, for the reason that the stream of heated air rising from the wire is very unstable, and is markedly influenced by the presence of slight air-currents, or draughts, in the neighboring atmosphere. Such a wire forms, in fact, a very sensitive draught detector. On the other hand the precision of forced convection measurements is distinctly higher, except at very low wind velocities.

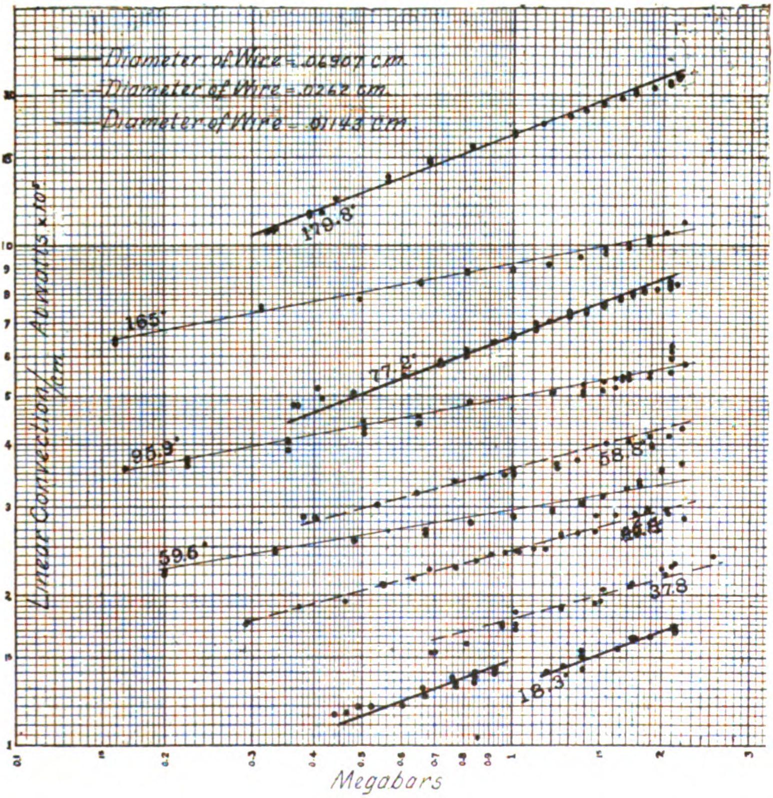

Fig. 6.—Linear convection for different wires at varying air-pressures

The complete expression of the linear free convection from a thin copper wire supported horizontally in substantially still air was, therefore, from the foregoing results:

$$P_c = (4{,}000 + 64{,}000\, d)\, \theta\, p^{0.9\sqrt[3]{d}} \quad \text{abwatts per cm.} \qquad (14)$$

Measurements of Forced Convection

General plan. In order to measure forced convection, the test wire was mounted between the prongs of a long fork, which was fastened at right-angles to a shaft driven by a motor at a regulated speed. The test wire was thus forced to move transversely through the air at a known velocity. This was taken as equivalent to a wind of the same velocity moving past the stationary wire. Electric connection was maintained with the moving wire through pairs of slip rings and brushes, one pair of slip rings carrying the testing current through the moving wire, while another pair served to maintain pressure connections with taps near the ends of the wire. The wire was maintained at a constant temperature during each series of tests by keeping its resistance constant; that is, by keeping constant the ratio of the potential difference between taps to the testing current, (E/I). The square of the current, multiplied by the linear resistance of the wire at the working temperature, then gave the linear dissipation in the wire at the observed velocity. The linear dissipations reduced by the computed linear radiations, gave the corresponding linear convections at the observed velocities.

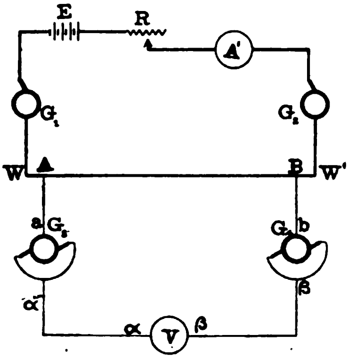

FIG. 7.—Electrical connections used in measurements of forced convection

Electrical connections. The electrical connections are indicated in Fig. 7. $W\,W'$ is the test-wire in the main circuit of the storage battery E, (from 8 to 15 volts), A' the ammeter, R the controlling resistance, and $G_1\,G_2$ the slip rings, with their copper gauze brushes. At the points $A\,B$, taps were soldered to the test-wire, and brought into connection with the voltmeter V through the wires Aa, Bb, the slip-rings $G_3\,G_4$, and their copper-gauze double-brushes.

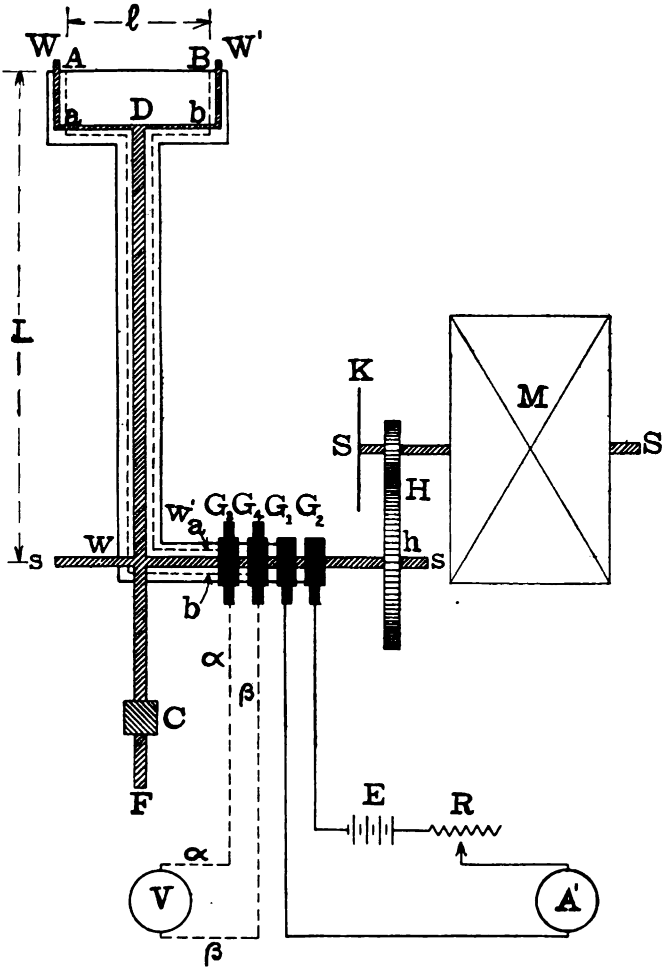

FIG. 8.—Mechanical and electrical connections used in measurements of forced convection

Mechanical and electrical connections. In Fig. 8, the test-wire *W W′* is shown in place in the fork *D F*, the details of the support being indicated in Fig. 9. This fork is made of a steel tube of 1.9 cm. (¾ in.) external diameter and 1.63 cm. (0.64 in.) internal diameter, 274 cm. (9 feet) long, mounted in the shaft *s s*, which is driven by the motor shaft *S S* through the velocity-reducing gear-wheels *H*, *h*. When adjusted in position, the wire *W W′* stood parallel to the shafts *s s*, *S S*. The radius *L* of the test-wire from the axis of the shaft *s s* was adjustable between certain limits. The usual radii selected were about 118 cm. (46.5 in.) and 180 cm. (70.8 in.), respectively. This change in radius not only enabled high and low velocities to be more easily attained; but also enabled the same velocity to be secured with two radii, as a check upon the observations. A suitable counterpoise *C* had to be used in each case.

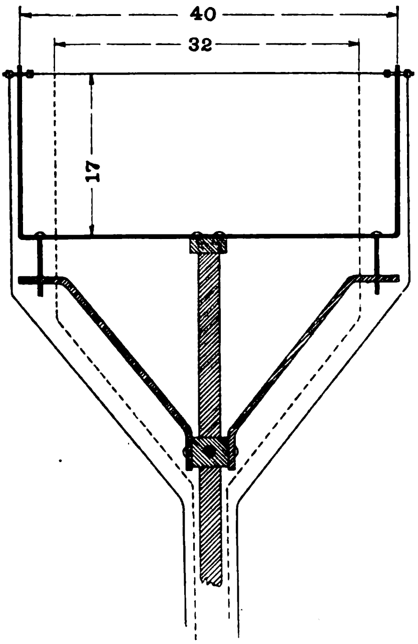

Fig. 9.—Details of fork. Dimensions in centimetres

The motor *M* was a ½-h.p., 115-volt, 4-pole machine, running at 1200 rev. per min. Its speed of rotation was controlled, in the usual way, by resistances in its field and armature circuits, not shown in the illustrations. The velocity-reducing gear ratio of 18/120, enabled the fork-shaft to make 180 rev. per min., when the motor-shaft made 1200 rev. per min. The four slip-rings were of brass, each 4 cm. (1.57 in.) in diameter, and 1.5 cm. (0.58 in.) wide. The copper gauze brushes resting on them were 3.8 cm. (1.5 in.) long, 0.95 cm. ($\frac{3}{8}$ in.) wide and 0.67 cm. (0.26 in.) thick. The brushes were soldered to their respective connecting wires, and were spring-pressed into contact with their slip rings. As an extra precaution, two brushes were used on each of the voltage slip rings G_3 G_4.

The voltmeter V and ammeter A^1 were standard portable instruments, specially calibrated for these tests. The frame on the end of the fork supporting the test wire is represented in detail in Fig. 9. It was made of brass strip 1.9 cm. ($\frac{3}{4}$ in.) broad and 0.32 cm. ($\frac{1}{8}$ in.) thick, so arranged as to disturb the air in the immediate neighborhood of the test-wire as little as possible during the motion.

An illustration of the general apparatus is given in Fig. 13, reproduced from a photograph.

Sample series of measurements. In making a series of tests on a test wire, the temperature elevation of the wire was selected in advance, and the resistance of the wire for that temperature elevation was computed by equation (1) from its resistance at the room temperature. A slide-rule was then set to this resistance, in such a manner that for any current strength through the wire, the corresponding potential difference required by Ohm's law could be read off directly. The fork radius L, Fig. 8, was then set, and the motor M brought into action. The speed of the motor-shaft was then adjusted to a suitable value. All speeds except the lowest were measured by means of an electromagnetically driven stroboscopic fork*, and through the slits in its vibrating shutters, a target K, mounted on the motor-shaft, was observed. The speed could thus be measured, with all desired accuracy, within from three to fifteen seconds after bringing the fork to the eye. The current was then increased until the correct current-voltage ratio was obtained, the speed again observed, and all three values recorded.

Each series comprised two different fork radii (L, Fig. 8), in such a manner that both radii were in use over a certain range of speed.

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* The Measurement of Rotary Speeds of Dynamo Machines by the Stroboscopic Fork. By A. E. Kennelly and S. E. Whiting, PROCEEDINGS American Institute Electrical Engineers, June, 1908, pp. 727–742.

Table IV contains a sample series of observations.

Column I gives the velocity of the wire, perpendicular to its length, through the air, or the "wind-velocity" using the formula:

$$v = 2\pi L N \qquad \text{cm. per sec.} \qquad (15)$$

TABLE IV

SAMPLE SERIES OF FORCED CONVECTION TEST

Run on wire of 2.038×10^{-2} cm. diameter.

Resistance held at 2.5×10^{8} absohms, giving 128.3 degrees cent elevation.

Barometer 770.4 mm. @ 18.6 degrees cent.

Average room temperature, 21 degrees cent.

Assmann aspiration psychrometer gave readings for $t = 20.2$ degrees cent. and $t' = 12.6$ degrees cent. .

Pressure 6.977 mm. corresponding to 0.905% or 9.05 l. of water-vapor per cubic meter ot air.

I Wind velocity v cm./sec.	II I Abs. amp.	III I^2 Abs. amp.^{2}	IV $P = I^2 r_T$ Linear power $\frac{\text{Abwatts}}{\text{cm.}}$	V P_r Linear radiation Abwatts cm.	VI P_c Linear convection Abwatts cm.	VII P'_c/θ Linear convection per degree cent. elevation	VIII $k = P'_c/(\theta\sqrt{v})$ Linear convection per degree cent. elevation and per $\sqrt{v}$
	$\times 10^{-1}$	$\times 10^{-1}$	$\times 10^{6}$		$\times 10^{6}$	$\times 10^{4}$	10^{3}
0	3.4	1.156	0.903	7.763×10^{4}	0.825	0.643	
114	5.6	3.136	2.450		2.372	1.849	1.731
205.7	6.2	3.844	3.003		2.926	2.280	1.591
330.5	6.8	4.624	3.613		3.535	2.755	1.515
522	7.5	5.625	4.394		4.316	3.364	1.472
395	7.05	4.970	3.884		3.807	2.967	1.493
561	7.5	5.625	4.394		4.316	3.364	1.420
708	8.0	6.400	5.000		4.923	3.837	1.442
880	8.5	7.225	5.645		5.567	4.340	1.463
1113	9.05	8.190	6.400		6.322	4.928	1.477
1321	9.42	8.874	6.931		6.853	5.342	1.470
775	8.3	6.889	5.382		5.305	4.135	1.485
1072	9.0	8.100	6.328		6.250	4.872	1.488
1383	9.55	9.120	7.127		7.049	5.494	1.477
1632	9.95	9.900	7.734		7.656	5.968	1.477
1862	10.35	10.712	8.368		8.291	6.463	1.498
0	0	1.225	0.957		0.879	0.685	

where L is the fork radius (Fig. 8) in cm., N is the speed of the fork-shaft in rev. per sec., and v is the wind-velocity in cm. per sec.

Column II gives the observed current, in absamperes through the wire, required to maintain its correct linear resistance in absohms per cm. at the working temperature T degrees cent.

Column III gives the current squared, expressed in absamperes squared. Column IV gives the linear dissipation in abwatts per cm. ($P = I^2 r_T$). Column V gives the linear radiation computed from the formula:

$$P_r = o\,\sigma\,(T_a^4 - t_a^4) \quad \text{abwatts per cm.} \qquad (16)$$

where o is the circumference of the wire in cm., σ is Stefan's coefficient, taken as 5×10^{-5} abwatts per sq. cm. and degree absolute. T_a is the absolute working temperature of the wire, and t_a the absolute temperature of the surrounding air. Column VI gives the linear convection $P_c' = P - P_r$, obtained by deducting the computed radiation from the linear dissipation. Column VII gives P_c'/θ or the linear convection divided by the inferred temperature elevation of the test-wire. The last column gives $P_c'/(\theta\sqrt{v})$ or the quotients obtained by dividing P_c'/θ by the square root of the wind velocity. It will be observed that except for the lowest wind velocity of 114 cm. per sec. the entries in the last column are seen to be substantially constant near 1.497×10^3.

TABLE V

PARTICULARS OF COPPER WIRES USED IN MEASUREMENTS OF FORCED CONVECTION

Wire No.	Diameter		Length between taps cm.	Cross-sectional area cm.^{2}	Linear surface cm.^{2}	Linear resistance @ 20 degrees cent. absohms/cm.	Linear resistance @ 0 degrees cent. absohms/cm.	Resistivity @ 0 degrees cent. absohm–cm.
	Cm.	Inches						
1	0.01008	0.004	32.5	0.7971×10^{-4}	3.167×10^{-2}	2.18×10^7	2.011×10^7	1603
2	0.0159	0.0063	31.6	1.985 "	4.995 "	0.8703 "	0.8028 "	1594
3	0.02038	0.008	32.0	3.262 "	6.402 "	0.5219 "	0.4815 "	1600

Copper wires. The accompanying table presents the dimensions of the copper wires employed in the measurements of forced convection.

Correction for linear radiation. It will be observed that in the case presented in Table IV, the computed linear radiation P_r' is only 3% of the linear dissipation P at the lowest recorded speed—114 cm. per sec.—and is only about 1% of the linear dissipation at the highest recorded speed—1862 cm. per sec.

This is a fair sample of the relation between the linear radiation and dissipation for all of the wires used. It shows that whereas the error due to incorrect estimation of σ, which might enter into the results for free convection, would be small but appreciable, the corresponding error in the results for forced convection would be practically quite inappreciable.

Results of measurements of forced convection. Out of the 16 series of measurements at different dates on the three test wires, all of which are in good agreement, 10 series are plotted on the logarithmically scaled chart shown in Fig. 10. The ordinates are in current units of amperes, or of 10^{-1} absamperes, (2 to 20 amperes) and the abscissas in units of wind-velocity of 10^2 cm. per sec., (200 to 2000 cm. per sec.). It will be observed that, except at the lowest velocities, the observations conform closely to straight lines whose inclinations with the abscissa axis are all 14°, or $\tan^{-1} 0.25$; so that the observations indicate a relation

$$I_\theta = K_\theta \sqrt[4]{v} \qquad \text{absamperes} \qquad (17)$$

in which K_θ is a constant for each wire and temperature elevation θ. The diameter of the wire is indicated by the type of line in Fig. 10, and the temperature elevation of the series in degrees cent. is marked on each line.

In Fig. 11 the results for the same ten series are plotted as linear convections in ordinate units of 10^6 abwatts per cm., against wind-velocity in abscissa units of 10^2 cm. per second. The lines are here inclined at an inclination of $26\frac{1}{2}° = \tan^{-1} 0.5$, and the results indicate a relation for linear convection:

$$P_c' = K_\theta' \sqrt{v} \qquad \text{abwatts per cm.} \qquad (18)$$

where K_θ' is a constant for each size of wire and temperature elevation θ.

Equations (17) and (18) cease to hold below wind velocities of 200 cm. per sec., apparently for the reason that these equations require zero linear convection at zero wind velocity, or stationary air. But free convection continues under the latter condition; so that these equations fail at low velocities by ignoring the influence of free convection.

The following table summarizes the results for the ten series of observations presented graphically in Figs. 10 and 11.

Column III gives the temperature elevation in degrees cent.
" IV " " linear convection from Fig. 11 for v = 900 cm./sec.
" V " $K_\theta' = P_c'/\sqrt{900} = P_c'/30$ abwatts per cm and cm./sec.
" VI " $k = K'/\theta$ abwatts per cm. for unit speed and 1 degree cent. elevation.

It appears, therefore, that for wire No. 1 the linear convection is:

$$P_c' = 884\,\theta\sqrt{v} \qquad \text{abwatts per cm.} \qquad (19)$$

TABLE VI

I Test wire No.	II Diameter. cm.	III Temperature elevation. θ deg. cent.	IV Linear convection P'_c for v = 900. abwatts/cm.	V K'_θ for v = 900. abwatts/cm	VI k abwatts per cm. and deg. cent. elevation	VII Mean k
1	0.01008	106.05	2.81×10^6	0.9366×10^5	883	884
		179.	4.63 "	1.547 "	864	
		251.8	6.83 "	2.277 "	904	
2	0.0159	117.4	4.16 "	1.387 "	1181	1212
		211.1	7.74 "	2.58 "	1222	
		305.	11.28 "	3.76 "	1233	
3	0.02038	51.	2.225 "	0.7416 "	1454	1475
		128.3	5.76 "	1.92 "	1497	
		205.5	9.08 "	3.027 "	1473	
		282.8	12.52 "	4.173 "	1476	

for wire No. 2:

$$= 1212\,\theta\sqrt{v} \qquad \text{abwatts per cm.} \qquad (20)$$

and for wire No. 3:

$$= 1475\,\theta\sqrt{v} \qquad \text{abwatts per cm.} \qquad (21)$$

Consequently, between the limits of v = 200 and v = 2000 cm. per sec. (4.5 and 45 miles per hour), and up to temperature elevations of 300 degrees cent., the linear forced convection is expressed by

$$P_c' = k\,\theta\sqrt{v} \qquad \text{abwatts per cm.} \qquad (22)$$

where k increases nearly in direct proportion to the diameter. A first approximation to the forced linear convection for a small wire of diameter d cm. would be:

$$P_c' = 76{,}000\, d\, \theta \sqrt{v} \qquad \text{abwatts per cm.} \qquad (23)$$

If we attempt a second approximation, which will more nearly satisfy equations (19) (20) and (21), we obtain:

$$P_c' = (300 + 58{,}000\, d)\, \theta \sqrt{v} \qquad \text{abwatts per cm.} \qquad (24)$$

Influence of water vapor in the air upon forced linear convection. On the occasion of each series of observations, a measurement of the amount of water-vapor in the air of the room was made by means of an Assmann psychometer, in which a fan driven by clock-work forces air over the wet and dry bulbs of a pair of thermometers placed side by side. The amount of water-vapor varied between 5.8 and 13.8 liters per cubic meter, on different days.

One or two measurements were taken with the air almost completely saturated with moisture after boiling water in the room for some hours. The object was to ascertain whether the presence of the water-vapor in excess appreciably altered the linear forced convection. It was found that starting with a clean test wire 0.0159 cm. in diameter, worked at 70 degrees cent. elevation in normally dry air, at a barometer reading of 778 mm., the series obtained was

$$P_c' = 1255\, \theta \sqrt{v} \qquad \text{abwatts per cm.} \qquad (25)$$

The next day, with moisture-saturated air and a barometer reading of 772 mm., the series obtained was about

$$P_c' = 1210\, \theta \sqrt{v} \qquad \text{abwatts per cm.} \qquad (26)$$

At first sight the reduction of about 4% seemed attributable to the excess of water-vapor; but it was found that the test wire had become decidedly blackened and superficially oxidized by being driven in the moist air. On repeating the series on the day following, with the same wire in normally dry air, at a barometer reading of 765 mm., the series obtained was:

$$P_c' = 1210\, \theta \sqrt{v} \qquad \text{abwatts per cm.} \qquad (27)$$

or the same as in the saturated air. Consequently, the effect of moisture in the air was relatively small, and was masked by the influence of changes in surface condition of the test wire or changes in the barometric pressure. The observations have not yet even served to determine whether the linear forced convection is increased or diminished by the presence of water-vapor.

Correction for free convection at low wind velocities. If formulas (23) and (24) are applied to the case of the test wire at rest and subject only to free convection, using the value of k obtained with higher wind velocities, we obtain a certain fictitious value of v which may be called the virtual wind-velocity of free convection. It is a matter of interest to examine this virtual velocity in the different series of observations. They are presented in the following table:

TABLE VII

VIRTUAL WIND VELOCITIES OF FREE CONVECTION FOR DIFFERENT TEST WIRES

I Diameter of test wire cm.	II Temperature elevation θ degree cent.	III Constant k abwatts/cm. per degree cent. and unit velocity	IV Linear free-convection $v = 0$ abwatts per cm. and degree cent.	V Virtual wind velocity v' cm. per sec.	VI Mean v' cm. per sec.
0.01008	106.05	883	4640	27.5	27.5
	"		4790	29.3	
	"		4438	25.4	
	179	864	3968	21.1	
	"		4794	30.7	
	251.8	904	4739	27.5	
			5042	31.0	
0.0159	117.4	1181	5269	20.0	22.9
	"	"	5420	21.0	
	117.4	"	5395	20.8	
	"	"	5777	23.8	
	211.1	1222	6072	24.7	
	"	"	5850	22.9	
	"	"	5850	22.9	
	305	1233	6016	23.7	
	"	"	6660	29.1	
0.02038	51	1454	5515	14.4	20.7
	"	"	6354	19.1	
	128.3	1497	6434	18.5	
	"	"	6855	21.0	
	205.5	1473	6818	21.5	
	"	"	7196	23.8	
	282.8	1476	7018	22.6	
	"	"	7378	25.0	

Column II gives the temperature elevation of the test, column III the values of k deduced for that test in Table VI. The linear convection per degree cent. elevation with the wire at rest is given in Column IV. This is linear free convection; but, treating the convection as though it were due to wind velocity, we obtain the values of the virtual wind velocity given in Column V, with the mean values for each wire in Column VI. It appears that the virtual wind velocity is independent of the temperature elevation and that it is about 23 cm. per second. It is independent of the size of wire to a first approximation; but is slightly lowered by increasing the wire diameter.

If we increase all of the actual wind velocities by 25 cm. per second, so as to correct for free convection, we obtain an empirical formula which conforms satisfactorily with the observations not only between the speed limits of 200 and 2000 cm. per sec., but also down to zero speed. We obtain from (23):

$$P_c' = 76{,}000\, d\, \theta \sqrt{v + 25} \qquad \text{abwatts per cm.} \qquad (28)$$

or taking formula (24) as more nearly representing the observations, we have:

$$P_c' = (300 + 58{,}000\, d)\, \theta \sqrt{v + 25} \qquad \text{abwatts per cm.} \qquad (29)$$

Possible application to anemometry. The law indicated by the results above stated, that the linear forced convection from a thin copper wire is proportional to the temperature elevation and to the square root of the wind velocity, after allowing a small correction for free convection, may be capable of application to the measurement of wind-velocities. It would probably be necessary to maintain a constant surface condition for the test wire by gilding or platinizing it, in order to keep the wire from oxidizing. A short vertical test wire carrying, say, constant-current strength under 110 volts, and with a steadying resistance of German-silver in its circuit, to absorb all but 6 volts, would fall in temperature and in resistance with an increase of the horizontal component of the wind. A recording voltmeter, connected to pressure taps near the ends of the test-wire, would leave a record that would be interpretable in wind-velocity. The instrument would have the maximum sensitiveness at low wind velocities and the sensitiveness would diminish as the wind velocity increased. Or, the test-wire might be worked at constant voltage of, say, 6 volts from a storage battery, and a recording ammeter in circuit with the wire would leave a record interpretable in wind velocity.

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Summary of experimental results. From the measurements above described on the dissipation of heat from thin copper wires (diameters 0.1 to 0.7 mm., or 4 to 27 mils) the following facts may be stated for conditions of free convection in a tank:

At constant standard air-pressure of 1 atmosphere, the linear convection was proportional to the temperature elevation of the wire, and was in the neighborhood of 6,000 abwatts (6×10^{-4} watt) per linear cm. per degree cent. and, to a first approximation, independent of the size of wire, although increasing slowly with the diameter. The results do not yet warrant a decision as to the precise increase with diameter, but it represented about $4{,}000 + 64{,}000\,d$ abwatts per cm., where d is the diameter in cm.

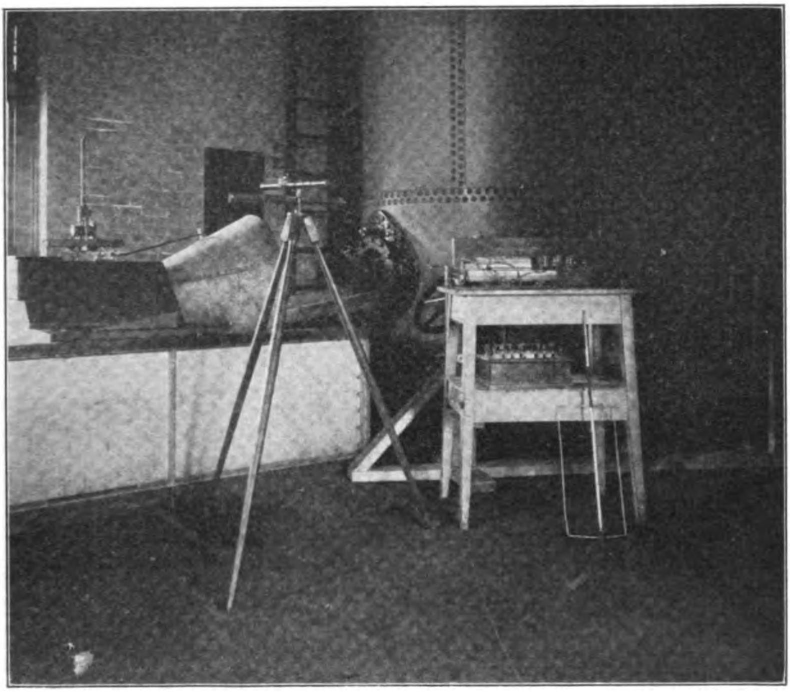

FIG. 12.—Apparatus in free convection tests.

Under varying atmospheric pressure, the linear convection increased with the pressure, substantially according to an exponential law, or to a straight line on logarithm paper, the exponent being the same for the same wire at different temperature elevations but with different wires increasing slowly with the diameter of the wire, or, to a first approximation, as the cube root of the diameter.

The current strength required to maintain a wire at constant temperature under free convection in varying atmospheric pressure, followed an exponent of the pressure, or a straight line on logarithm paper, the exponent being the same for different temperature elevations (up to 180 degrees cent.) of the same wire, but increasing slowly with the diameter of the wire.

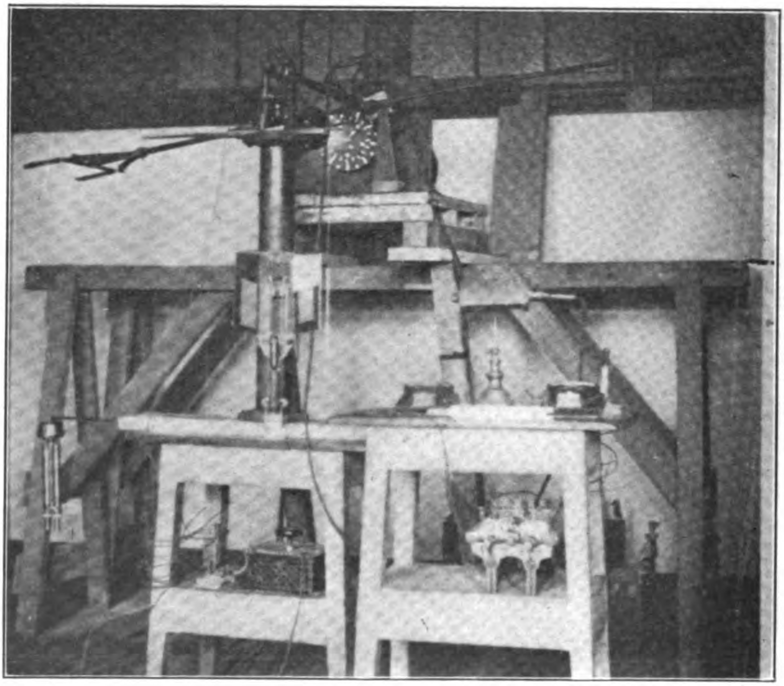

FIG. 13.—Apparatus in forced convection tests.

For conditions of forced convection, or wind, on a thin wire, the following observations may be stated:

The linear convection was proportional to the temperature elevation of the wire at the same wind velocity.

The linear convection, at any single wind velocity between 200 and 2000 cm. per second, increased with the size of wire and, as a first approximation, in direct proportion to the wire diameter.

Under varying wind velocities, within the range of 200 to

2000 cm. per second, the linear convection increased as the square root of the wind-velocity.

At wind-velocities below 200 cm. per second, the linear convection was greater than that predicted by the last preceding rule, apparently owing to the presence of free convection in air not moved by an external force.

The free convection from the wires at rest corresponded to a forced convection at a virtual wind-velocity of about 25 cm. per second. To a first approximation this virtual wind velocity of free convection was constant for the different temperature elevations, and also for the different sizes of thin wire tried; but it diminished slightly as the diameter of the wire increased.

The correction for radiation on a wire of 0.2 mm. diameter in a wind velocity of 500 cm. per second was less than 2 per cent.

The linear convection from a wire under a wind velocity of 2000 cm. per second was nine times that when the wire was at rest.

If a virtual wind velocity of 25 cm. per second, for free convection, be added to all the actual wind velocities in forced convection tests, the linear convections conform satisfactorily to the law of square roots of wind velocity from 2000 cm. per sec. down to 0 cm. per sec.

A thin layer of oxide on the wire slightly diminished the forced convection.

List of Symbols Employed

A_θ, B_θ = constants of linear free convection, abwatts and absamperes per cm. at 1 megabar.

a, b, c = constants of linear free convection, abwatts per cm. per degree cent. at 1 megabar.

d = diameter of test-wire, cm.

$G\,G'$ = resistances of differential galvanometer coils, ohms or absohms.

I_θ = current strength in test-wire at $\theta°$ cent, temperature elevation, absamperes.

$K_\theta\,K_\theta'$ = constants of linear forced convection, absamperes and abwatts per cm. at 1 cm. per sec.

k = constant of linear forced convection, abwatts per cm. per deg. cent., at 1 cm. per sec.

N = rotary speed of fork-shaft, revs. per sec.

m, n = exponents of the atmospheric pressure, numerics.

o = circumference of a test wire, cm. = linear surface of a test wire, sq. cm./cm.

p = atmospheric pressure, megabars.

R = resistance of test wire, ohms or absohms.

R' = Constant comparison resistance of German silver, ohms or absohms.

R_0 = Resistance of a test wire at 0° cent., absohms.

R_T = Resistance of a test-wire at T° cent., absohms.

r = Linear resistance of a test-wire, absohms.

r_T = Linear resistance of a test-wire at T degrees cent., absohms.

ρ = adjustable resistance in galvanometer circuit, ohms, or absohms.

σ = Stefan's coefficient, abwatts per sq. cm. per degree absolute.

$P = I_\theta^2 r$ = linear dissipation of power in test-wire, abwatts per cm.

P_c = linear free convection from test-wire, abwatts per cm.

P_c' = linear forced convection from test-wire, abwatts per cm.

P_r = linear radiation from test-wire, abwatts per cm.

T_a = Temperature, in degrees absolute, of test-wire.

T = Temperature, in degrees cent., of test-wire.

t_a = Temperature, in degrees absolute, of surrounding bodies.

t = Temperature, in degrees cent., of surrounding bodies.

$\theta = T - t$ = Temperature elevation, degrees cent., of hot wire.

t' = Temperature in degrees cent. of wet bulb thermometer.

v = velocity of wind, cm. per second.

v' = virtual wind-velocity of free convection, cm. per second.

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THE CURRENT LOCUS OF THE SINGLE-PHASE INDUCTION MOTOR

BY A. S. LANGSDORF

The theory of the single-phase induction motor has, until recently, been complicated by the general use of Ferrari's expedient of resolving the impressed alternating magnetic field into forwardly and backwardly rotating components; this conception, though it leads to correct results if consistently handled, is open to the objection that it departs unnecessarily from the physical facts, and gives rise to the notion that the ordinary laws of electromagnetic induction are not immediately applicable, as in the direct-current machine. Within the last few years, however, the tendency in treating this problem has been to go back to first principles, and several valuable contributions have appeared, notably those of Fynn and McAllister. The following treatment has been based largely on the theory advanced by Fynn in his several publications.

I. *General principles and vector diagram.* The physical behavior of the single-phase induction motor having a permanently short-circuited or squirrel-cage rotor is identical with that of the motor shown diagrammatically in Fig. 1. This represents a stator of the usual cylindrical form with an embedded winding, and a wound rotor provided with a commutator. Two sets of brushes, short-circuited in pairs, are provided, the one set being magnetically in line with the axis of the stator winding, and the other at right angles thereto. Employing the usual nomenclature, the rotor axis *a a* will be referred to as the "transformer" or "armature" axis, while the axis *f f* will be called the "speed" or "field" axis. From the assumed construction of the magnetic circuit it follows that the reluctance will be the same along all axes, and that the resistance and leakage reactance of the rotor will be the same in both the transformer and speed axes.

Under standstill conditions the stator winding and the rotor winding along the axis *a a* constitute a short-circuited transformer whose magnetic circuit is " leaky " owing to the air-gap. But under any conditions, at standstill or when running, the usual transformer relations must be satisfied so far as this axis of the motor is concerned; the stator current must supply the magnetomotive force to produce the flux demanded by the impressed electromotive force (modified by the drop due to primary local impedance) and it must balance the magnetomotive force of the rotor current in the transformer axis. Thus, at standstill, if Φ_t, Fig. 2, is the flux of mutual induction in the transformer axis there will be induced in both primary and secondary an electromotive force E_t lagging 90 degrees behind Φ_t (assuming unity ratio of transformation or that the secondary has been reduced to terms of the primary). A current i_t will then flow in the axis *a a* of the rotor, being determined in magnitude and phase by the local impedance of the rotor. The primary current, i_1, will then be the resultant of i_0, the magnetizing current, and of i_t reversed. The impressed electromotive force, E_1, will be the resultant of a component equal and opposite to E_t and of a component $i_1 z_1$ to overcome the local impedance, z_1, of the stator.

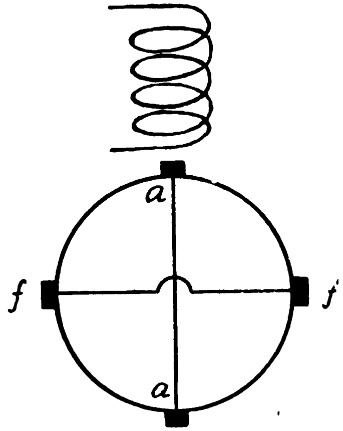

FIG. 1

If the motor be brought up to speed in some way, there will be generated* an electromotive force E_t' (Fig. 3) of line frequency, in the speed axis, ff. The magnitude of E_t' will be proportional to Φ_t and the speed, and it will be either in time-phase with, or time-phase opposition to, the flux Φ_t, depending upon the direction of rotation. Let it be assumed to be in time-phase with Φ_t. The rotor current, i_t, in the transformer axis, also sets up a leakage field (ϕ_t) in phase with itself, stationary in space, and coaxial with Φ_t; hence there will also be generated in the speed axis an electromotive force e_t', in time phase with i_t and proportional to ϕ_t and the speed. The resultant electro-

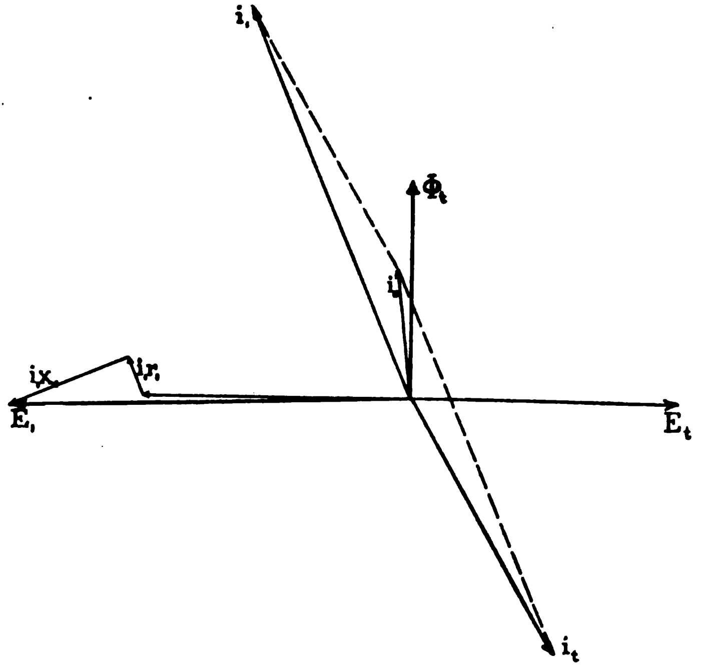

FIG. 2

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* The following system of nomenclature has been used: Main fluxes are represented by (capital) Φ, with appropriate subscripts; leakage fluxes by ϕ. Electromotive forces *induced* by a main flux are capitalized and bear the same subscript as the inducing flux; electromotive forces *generated* by a main flux are capitalized and primed; electromotive forces due to leakage fluxes are similarly designated, except that lower case is used.

motive force in the speed axis is then E_f, compounded vectorially of E_t' and e_t'.

Inasmuch as the conditions along the speed axis are those of a transformer on open circuit, the electromotive force E_f will set up a current i_s lagging heavily, and this will produce a magnetic "speed field," Φ_s, nearly in quadrature with E_f. The speed field, by its alternation through the rotor winding, will induce in the speed axis an electromotive force E_s lagging behind Φ_s by a quarter period, hence E_f must contain, as one component, an electromotive force equal and opposite to E_s; the other component of E_f drives the current i_s through the local impedance of the rotor. The relations between E_f, i_s, Φ_s and E_s are shown separately in Fig. 4 to avoid confusion in Fig. 3.

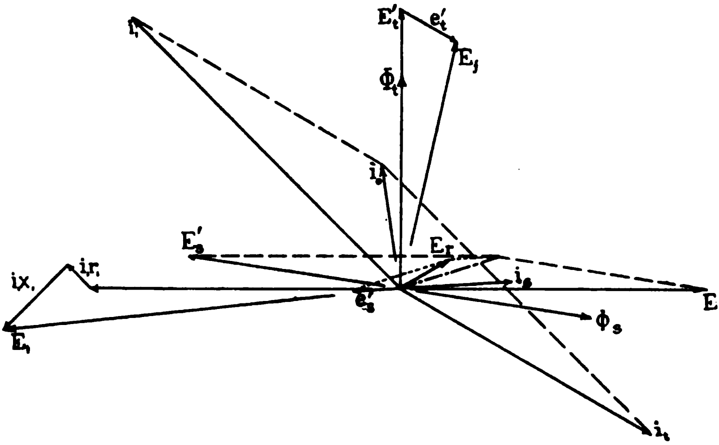

FIG. 3

The motion of the rotor conductors through the speed field generates in the transformer axis an electromotive force E_s' which is in time-phase opposition to Φ_s, and, therefore, nearly opposed to E_t. E_s' is the equivalent of the counter electromotive force of the continuous-current motor. The speed-field current i_s also produces a small leakage flux (ϕ_s) coaxial with Φ_s and in time phase with i_s; hence there is a third electromotive force, e_s', in the transformer axis which is opposite in phase to i_s and proportional to ϕ_s and the speed. The electromotive force e_s' is small, but not necessarily neglible, especially near synchronism. The vector sum of E_t, E_s' and e_s', represented in Fig. 3 by E_r, then serves to drive the current i_t through the local impedance of the rotor.

II. Mathematical Treatment.

Collecting symbols, let

E_1 = primary impressed electromotive force.
i_0 = primary exciting current—rotor on open circuit.
i_1 = total primary current.
Φ_t = transformer flux.
Φ_s = speed flux.
E_t = electromotive force induced by Φ_t.
E_t' = electromotive force generated by Φ_t.

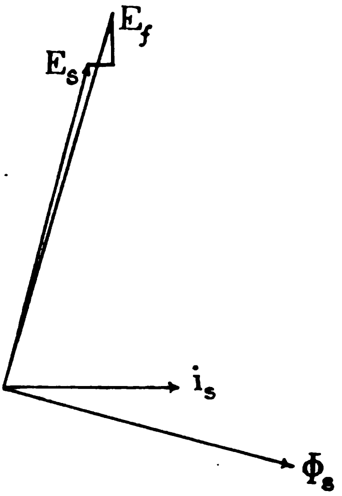

FIG. 4

E_s = electromotive force induced by Φ_s.
E_s' = electromotive force generated by Φ_s.
i_t = rotor current in transformer axis.
i_s = rotor current in speed axis.
ϕ_t = leakage flux due to i_t.
ϕ_s = leakage flux due to i_s.
e_t' = electromotive force generated by rotation through ϕ_t.
e_s' = electromotive force generated by rotation through ϕ_s.
$z_1 = r_1 + j\,x_1$ = primary local impedance.
$z_0 = 1/y_1$ = primary exciting impedance.
$y_1 = g_1 - j\,b_1$ = primary exciting admittance.
$z_2 = r_2 + j\,x_2$ = secondary (rotor) local impedance.

$z_s = 1/y_2$ = secondary exciting impedance.
$y_2 = g_2 - j\,b_2$ = secondary exciting admittance (speed axis).
S = speed with synchronism as unity.

A little consideration will show that $e_t' = S\,x_2\,i_t$ and that $e_s' = S\,x_2\,i_s$ and that vectorially (see Fig. 3)

$$\underset{\cdot}{e_t'} = S\,x_2\,\underset{\cdot}{i_t} \tag{1}$$

$$\underset{\cdot}{e_s'} = -S\,x_2\,\underset{\cdot}{i_s} \tag{2}$$

From Figs. 3 and 4 it is seen that

$$\underset{\cdot}{E_f} = \underset{\cdot}{E_t'} + \underset{\cdot}{e_t'} = \underset{\cdot}{E_s} + \underset{\cdot}{i_s}\,z_2$$

or

$$\underset{\cdot}{E_s} = \underset{\cdot}{E_t'} + \underset{\cdot}{e_t'} - \underset{\cdot}{i_s}\,z_2 \tag{3}$$

But

$$\underset{\cdot}{i_s} = \underset{\cdot}{E_s}\,y_2,$$

hence from (1) and (3)

$$\underset{\cdot}{E_s} = \frac{\underset{\cdot}{E_t'} + \underset{\cdot}{i_t}\,S\,x_2}{1 + z_2\,y_2} \tag{4}$$

From the ordinary equations of the transformer and the generator it follows that

$$\begin{aligned} E_t &= \kappa\,\Phi_t \\ E_t' &= S\,\kappa\,\Phi_t = S\,E_t \\ E_s &= \kappa\,\Phi_s \\ E_s' &= S\,\kappa\,\Phi_s = S\,E_s \end{aligned}$$

where κ is a constant, and vectorially

$$\underset{\cdot}{E_t'} = j\,S\,\underset{\cdot}{E_t} \tag{5}$$

$$\underset{\cdot}{E_s'} = j\,S\,\underset{\cdot}{E_s} \tag{6}$$

From Fig. 3 there results

$$\underset{\cdot}{Er} = \underset{\cdot}{E_t} + \underset{\cdot}{E_s'} + \underset{\cdot}{e_s'}$$

and upon substituting for E_s' and e_s' from (6), (5), (4) and (1) it follows that

$$\underset{\cdot}{E_r} = \underset{\cdot}{E_t}\left[1-\frac{S^2(z_s+j\,x_2)}{z_2+z_s}\right] + \underset{\cdot}{i_t}\left[\frac{j\,S^2\,x_2\,z_s - S^2\,x_2}{z_2+z_s}\right] \quad (7)$$

Substituting in (7) the relation $\underset{\cdot}{E_r} = \underset{\cdot}{i_t}\,z_2$,

$$\underset{\cdot}{i_t}\left[z_2-\frac{S^2(j\,x_2\,z_s-x_2^2)}{z_2+z_s}\right] = \underset{\cdot}{E_t}\left[1-\frac{S^2(z_s+j\,x_2)}{z_2+z_s}\right] \quad (8)$$

The primary current is determined by the condition

$$\underset{\cdot}{i_1} = \underset{\cdot}{i_0} - \underset{\cdot}{i_t} = -\underset{\cdot}{E_t}\,y_1 - \underset{\cdot}{i_t}$$

and the primary impressed e.m.f. is given by

$$\underset{\cdot}{E_1} = -\underset{\cdot}{E_t} + \underset{\cdot}{i_1}\,z_1;$$

hence

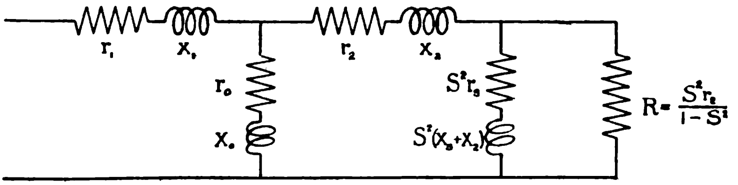

FIG. 5

$$\underset{\cdot}{E_1} = \underset{\cdot}{i_1}\left[z_1 + \cfrac{1}{y_1 + \cfrac{1}{z_2 + \cfrac{1}{\cfrac{1}{S^2(z_s+j\,x_2)} + \cfrac{1-S^2}{S^2\,r_2}}}}\right] \quad (9)$$

The expression in the bracket in equation (9) is the equivalent impedance of the motor. Its form shows that the equivalent circuit is as sketched in Fig. 5, in which the exciting circuits are shown as impedances, or as in Fig. 6 where the exciting admittances are drawn.

It is to be noted that the equivalent circuit as here derived differs from the one ordinarily described in that the exciting admittance of the speed field is not constant, but a function of the speed. At standstill ($S = 0$) and at synchronism ($S = 1$)

the circuit of Fig. 6 becomes the same as the commonly accepted diagram, but at all other speeds it differs therefrom. Consequently it is not at once obvious that it is admissible to transfer the exciting circuits to the terminals *a*, *b*, as is usually done.

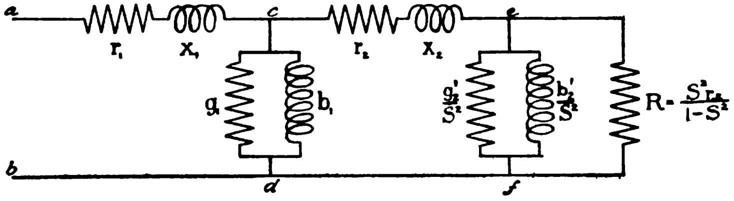

FIG. 6

Under these circumstances it is of interest to determine the form of the primary current locus, assuming that the so-called " constants " of the motor are unaffected by variations in the load and speed. It is purposed to determine this locus for the equivalent circuit of Fig. 6, just as it stands, and inserting

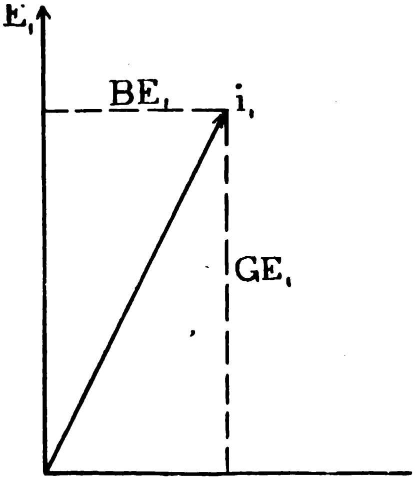

FIG. 7

simplifying approximations as the final step. It then becomes convenient to transform equation (9) into

$$\underset{\bullet}{i}_1 = \underset{\bullet}{E}_1\,(G - j\,B) \tag{10}$$

where *G* and *B* are, respectively, the equivalent conductance and susceptance of the machine. The impressed e.m.f. E_1 being constant, the equation of the current locus will be given by the relation between G and B and the motor constants.

Referring to Fig. 6 it is clear that between points a and b the conductance is G and the susceptance B; at (c, d) the resistance is $\frac{G}{G^2+B^2} - r_1$ and the reactance is $\frac{B}{G^2+B^2} - x_1$; proceeding in this way through the diagram there results the following table:*

Points	Conductance or Resistance	Susceptance or Reactance	Unit
a, b	G	B	mho
c, d	$\frac{G}{G^2+B^2} - r_1 = \alpha$ (11)	$\frac{B}{G^2+B^2} - x_1 = \beta$ (12)	ohm
c, d	$\frac{\alpha}{\alpha^2+\beta^2} - g_1 = \gamma$ (13)	$\frac{\beta}{\alpha^2+\beta^2} - b_1 = \delta$ (14)	mho
e, f	$\frac{\gamma}{\gamma^2+\delta^2} - r_2 = \varepsilon$ (15)	$\frac{\delta}{\gamma^2+\delta^2} - x_2 = \zeta$ (16)	ohm
e, f	$\frac{\varepsilon}{\varepsilon^2+\zeta^2} = \frac{g_2'}{S^2} + \frac{1-S^2}{S^2\, r_2}$ (17)	$\frac{\zeta}{\varepsilon^2+\zeta^2} = \frac{b'_2}{S^2}$ (18)	mho

Starting first with equation (17) and then with (18), and eliminating successively ε, ζ, γ, δ, α and β, there result

$$\frac{K}{L_1}\left(\frac{g_2'}{S^2} + \frac{1-S^2}{S^2\, r_2}\right)\left[\left(G - \frac{M}{K}\right)^2 + \left(B - \frac{P}{K}\right)^2\right]$$

$$+\left[\left(G - \frac{N_1}{L_1}\right)^2 + \left(B - \frac{Q_1}{L_1}\right)^2 - \frac{1}{4\, L_1^2}\right] = 0 \qquad (19)$$

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* The Exact Circular Current Locus of the Induction Motor, by K. J Laurell, *Electrical World*, Vol. 52, p. 78.

and

$$\frac{K}{L}\,\frac{b_2'}{S^2}\left[\left(G-\frac{M}{K}\right)^2+\left(B-\frac{P}{K}\right)^2\right]$$

$$+\left[\left(G-\frac{N}{L}\right)^2+\left(B-\frac{Q}{L}\right)^2-\frac{1}{4\,L^2}\right]=0 \qquad (20)$$

Where

$M = A\, r_1 + D$
$N = b_1\, r_1 + g_1\, x_2 + r_1\, x_2\, y_1^2$
$P = A\, x_1 + C$
$Q = b_1\,(x_1+x_2) + x_1\, x_2\, y_1^2 + \frac{1}{2}$
$K = A\, z_1^2 + 2\, D\, r_1 + 2\, C\, x_1 + z_2^2$
$L = x_1 + x_2 + z_1^2\,(b_1 + x_2\, y_1^2) + 2\, x_2\,(g_1\, r_1 + b_1\, x_1)$
$L_1 = r_1 + r_2 + z_1^2\,(g_1 + r_2\, y_1^2) + 2\, r_2\,(g_1\, r_1 + b_1\, x_1)$
$N_1 = g_1\,(r_1 + r_2) + r_1\, r_2\, y_1^2 + \frac{1}{2}$
$Q_1 = g_1\, x_1 + b_1\, r_2 + r_2\, x_1\, y_1^2$
$A = 1 + 2\, b_1\, x_2 + 2\, g_1\, r_2 + y_1^2\, z_1^2$
$D = r_2 + g_1\, z_2^2$
$C = x_2 + b_1\, z_2^2$

Eliminating S^2 between (19) and (20) it is found that

$$\left[G-\frac{M\,\frac{b_2'}{r_2}+N\left(g_2'+\frac{1}{r_2}\right)-N_1\, b_2'}{K\,\frac{b_2'}{r_2}+L\left(g_2'+\frac{1}{r_2}\right)-L_1\, b_2'}\right]^2$$

$$+\left[B-\frac{P\,\frac{b_2'}{r_2}+Q\left(g_2'+\frac{1}{r_2}\right)-Q_1\, b_2'}{K\,\frac{b_2'}{r_2}+L\left(g_2'+\frac{1}{r_2}\right)-L_1\, b_2'}\right]^2$$

$$=\frac{b_2'^2+\left(g'_2+\frac{1}{r_2}\right)^2}{4\left[K\,\frac{b_2'}{r_2}+L\left(g_2'+\frac{1}{r_2}\right)-L_1\, b_2'\right]^2} \qquad (21)$$

which is the equation of a circle.

In any well-designed motor terms involving y_1^2 may be neglected; g_2' is likewise negligible with respect to $1/r_2$; but in general it does not appear that any considerable simplification of the final equation (21) is possible, several trials having been made using the constants of different motors. It should be noted that the values of g_2' and b_2' are, respectively,

$$g_2' = \frac{r_s}{r_s^2 + (x_s + x_2)^2} \cong g_1$$

$$b_2' = \frac{x_s + x_2}{r_s^2 + (x_s + x_2)^2} \cong b_1$$

III. *Experimental results and conclusions.* In order to check the accuracy of equation (21), several test runs were made on a single-phase motor of standard make. The motor was rated at 5 h.p. at 104 volts and 60 cycles: its constants, determined in the usual way by open-circuit and short-circuit measurements, were found to be:

$$\begin{aligned} r_1 &= 0.079 \\ r_2 &= 0.167 \\ x_1 + x_2 &= 0.449 \\ g_1 &= 0.029 \\ b_1 &= 0.078 \end{aligned}$$

Hence,

$$\begin{aligned} A &= 1.045 & \qquad Q &= 0.535 \\ C &= 0.231 & K &= 0.265 \\ D &= 0.169 & L &= 0.462 \\ M &= 0.252 & L_1 &= 0.254 \\ N &= 0.013 & N_1 &= 0.507 \\ P &= 0.466 & Q_1 &= 0.020 \end{aligned}$$

The abscissa and ordinate of the center of the circle are, respectively,

$$\xi = E_1 \frac{P \dfrac{b_2'}{r_2} + Q\left(g_2' + \dfrac{1}{r_2}\right) - Q_1 b_2'}{K \dfrac{b_2'}{r_2} + L\left(g_2' + \dfrac{1}{r_2}\right) - L_1 b_2'} = 1.19\, E_1$$

$$\eta = E_1 \frac{M \dfrac{b_2'}{r_2} + N\left(g_2' + \dfrac{1}{r_2}\right) - N_1 b_2'}{K \dfrac{b_2'}{r_2} + L\left(g_2' + \dfrac{1}{r_2}\right) - L_1 b_2'} = 0.053\, E_1$$

and the radius is

$$\rho = E_1 \frac{\sqrt{b_2'^2 + \left(g_2' + \frac{1}{r_2}\right)^2}}{2\left[K\frac{b_2'}{r_2} + L\left(g_2' + \frac{1}{r_2}\right) - L_1 b_2'\right]} = 1.04\, E_1$$

The data of a run at a constant impressed electromotive force of 105 volts are plotted in Fig. 8, which shows a satisfactory agreement between the observed and the theoretical current locus. The coördinates of the center of the circle are

ξ = 125 amperes,

η = 5.56 amperes,

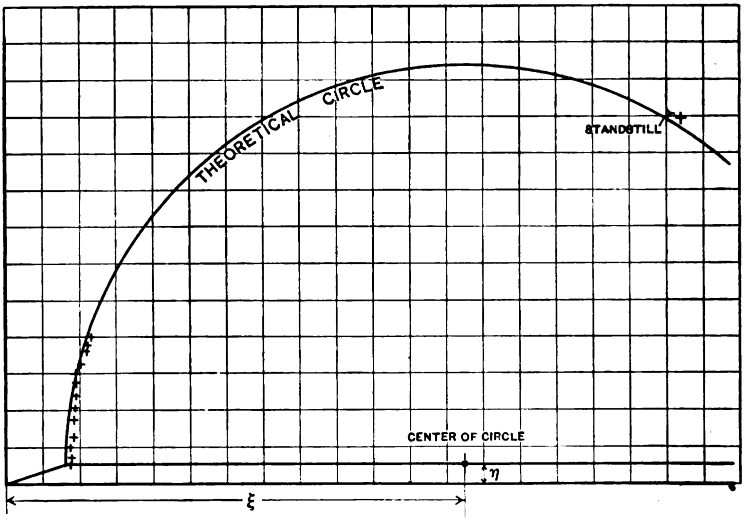

FIG. 8

and the radius is

ρ = 109 amperes.

It thus appears that statements to the effect that the current locus is a curve of higher order are in error. The locus is a true circle in spite of the complicated nature of the equivalent circuit, and it may be readily determined for any given motor by two simple measurements—primary current and power-factor with the rotor open-circuited, and the impedance voltage and power-factor with rotor blocked and short-circuited.*

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* The writer desires to express his indebtedness to Messrs. W. E. Beatty and I. A. Sims for assistance in obtaining experimental data.

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CORONA PHENOMENA IN AIR AND OIL AND THEIR RELATION TO TRANSFORMER DESIGN

BY W. S. MOODY AND G. FACCIOLI

Several experimenters have investigated the phenomena of corona and published very complete results of their investigations, which, however, have been confined almost entirely to the conditions found in transmission lines. The experiments recently made by the authors, some of which will be described in this paper, were not undertaken with any idea to add to the available information applicable to transmission lines, but rather with reference to apparatus, and especially static transformers.

In transmission lines we have the simplest form of a condenser to consider in studying the corona effects. In apparatus, the forms of condenser that must be considered are evidently very much more complex, because of the relatively shorter length of the dielectric, the irregular shapes of the condenser surfaces, and the combination of solid, liquid, and gaseous dielectrics.

No attempt will be made to make the paper an exhaustive treatise on the subject; in fact, the experiments have shown so many unexpected results that it would be quite impossible to do so from the experiments so far completed. It is hoped simply to bring out some confirmation of existing knowledge and some distinctly new observations, to point out the very complex nature of the study, and how essential further knowledge will become with the increasing demand for apparatus generating 100,000 volts and over.

The first series of tests were made on apparatus consisting of a cylindrical conductor parallel to a plate. Let us briefly recall the theory giving the distribution of the electric field in a condenser of this type.

The capacity of such a condenser is

$$C = \frac{1}{2 \log_n \dfrac{2D}{\rho}} \text{ c.g.s.}$$

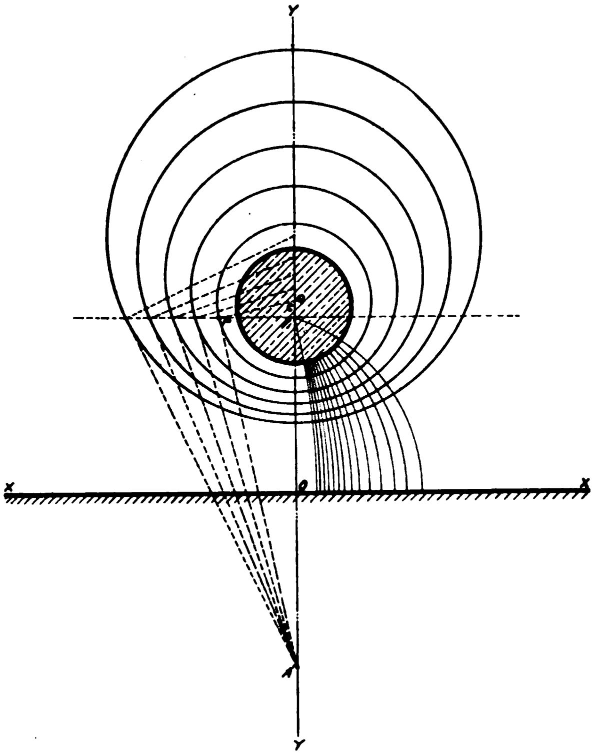

Fig. 1.

electrostatic units per unit length, where ρ is the radius of the conductor and D is the distance between the center of the conductor and the plate. This formula is sufficiently accurate if ρ is small with reference to D.

Fig. 1 represents such a condenser. The plate $x\,x$ is at a distance $C\,O$ from the cylindrical conductor. The diameter of the conductor has been chosen comparatively large in proportion to the distance from the plate in order to have a distinct picture of the equipotential surface, etc. The lines of force are circles with their centers on $x\,x$ and all pass through the points $A\,A'$, such that $O\,A = O\,A'$ and $C\,A = D - \sqrt{D^2 - \rho^2}$

The equipotential surfaces are represented in cross section by a series of circles perpendicular to the lines of force and with their centers along the axis $Y\,Y$. If we imagine these equipotential surfaces materialized and metallic, we do not change the distribution of the electric field in the condenser. If, therefore, we wish to know the potential existing at a point P, we can imagine that the condenser formed by the conductor and the equipotential surface passing through P, is in series with the condenser formed by this equipotential surface and the plate $x\,x$

The capacity between the cylindrical surface passing through P, and the plate $x\,x$ is given by.

$$c' = \frac{1}{2 \log_n \frac{2\,D}{m}}$$

where m is the radius of the equipotential cylindrical surface passing through P, m being supposed to be small with reference to D. The potential at the point P will then be

$$E' = E\frac{c'}{C} = \frac{E \log_n \frac{2\,D}{m}}{\log_n \frac{2\,D}{\rho}}$$

The potential of $x\,x$ is assumed as zero, and E is the potential applied to the cylindrical conductor. This formula is general and gives the potential of any point P in the field, provided m be small with reference to D.

If we want the potential gradient κ at any point P, we must take the first derivative of the potential and we arrive at

$$\kappa = \frac{1}{m} \frac{E}{\log_n \frac{2\,D}{\rho}}$$

and using the decimal logarithm we have

$$\kappa = \frac{1}{m} \frac{0.434\,E}{\log_{10} \frac{2\,D}{\rho}}$$

It is very important to know at which point of the field this potential gradient κ is maximum. Obviously κ is maximum for $m = \rho$, and the maximum gradient is therefore

$$\kappa_{max} = \frac{0.434\,E}{\rho \log_{10} \dfrac{2\,D}{\rho}}$$

The potential gradient is then a maximum at the surface of the conductor, and when κ maximum is higher than the resisting power of air, corona will appear on the conductor. From a number of experiments the maximum permissible stress in air at atmospheric pressure seems to be 100,000 volts per inch. The voltage at which corona will appear on a cylindrical conductor is therefore given by

$$E = \frac{100000}{0.434}\,\rho \log_{10} \frac{2\,D}{\rho} = 230000\,\rho \log_{10} \frac{2\,D}{\rho}$$

and using the effective value

$$E_{eff.} = 160000\,\rho \log_{10} \frac{2\,D}{\rho}$$

this being true for a sine wave.

Applying this formula to distances $D = 9$ in., 12 in., and 18 in., for diameters of conductors of $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{3}{8}$ in., and $\frac{1}{2}$ in., we obtain the following table of voltages necessary to establish corona under different conditions:

D	Diameter of conductor			
	0.125 in.	0.25 in.	0.375 in.	0.50 in.
9 in.	24600	43200	59400	74400
12 in.	25800	45600	63000	79200
18 in.	27600	49200	68400	86400

We must note that this formula does not take into consideration the temperature, barometric pressure and the vapor product; *i.e.*, it is assumed that the constant, 100,000 volts per inch, is regardless of temperature, barometric pressure or vapor product. To check the results of this formula experimentally the apparatus outlined in Fig. 2 was used. A rod 45 in. long is suspended by small bare copper wires *A C* and *B D* from pieces of treated wood hanging from the ceiling. A large iron plate 69 in. long and 27 in. wide, grounded, is brought at a distance *D* from the rod. The points *C* and *D* are connected by bare copper wire; the potential is brought in the wire *M* from the terminal of a transformer whose other terminal is grounded. The volts are read across the secondary of a transformer which is excited by a 60-cycle sine-wave generator. The capacity of the transformer is 100 kw. and by properly grouping the secondary coils, different ratios of transformation are obtainable.

The results given below are the average readings taken repeatedly over a period of two months. The readings taken at different times under the same conditions agree remarkably well. The variations of temperature and barometric pressure were very small, the average temperature being 23 degrees cent., and the average barometric pressure 28.9 in.

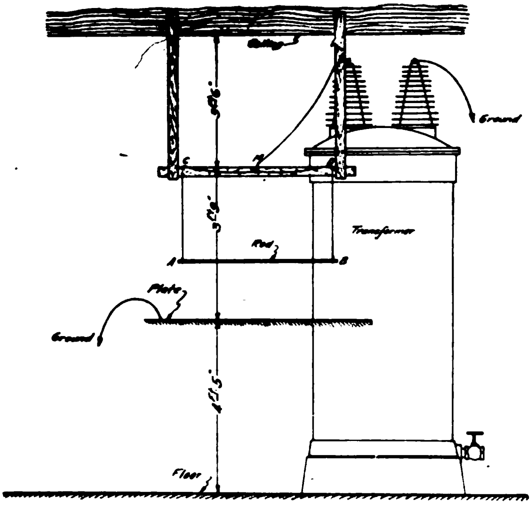

FIG. 2

It must be noted at this point that corona appears on the conductor very abruptly; furthermore, the luminous phenomenon is accompanied by the well-known characteristic noise, so that there is little chance for errors of observation.

The following table gives the voltages at which corona appears on the center of the rod in the apparatus illustrated in Figure 2.

D	Diameter of conductor			
	1.8 in.	0.25 in.	0.375 in.	0.50 in.
9 in.	**35600**	54500	69800	85000
12 in.	**38000**	57000	75000	90750
18 in.	**41200**	61000	80500	95000

The results are plotted in Fig. 3. The curve obtained from the tests is in all cases fairly parallel to the calculated theoretical curve, and the test values may be represented by the formula

$$E = 160000\,\rho \log_{10} \frac{2\,D}{\rho} + f$$

where f is a constant, whose value is 12000 volts. It is not surprising that this relatively small correction should be found necessary when attempting to apply a formula, which has been evolved for transmission lines, to such extreme conditions as existed in these experiments.

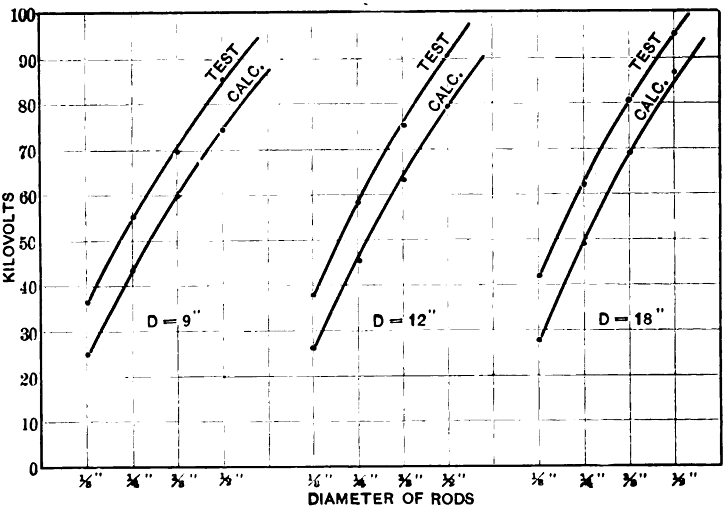

FIG. 3

Professor Ryan has given a formula to determine the conditions necessary for corona between two parallel cylindrical conductors. The maximum value of the voltage at which corona appears, according to this formula is

$$E_{max} = \frac{17.94b}{459.2 + t}\,350000\,(\rho + 0.07) \log_{10} \frac{s}{\rho}$$

where b is the barometric pressure in inches, t is the temperature in degrees Fahrenheit, ρ is the radius of the conductors and s the distance between conductors.

To apply this formula to our case we must divide E_{max} by 2; we will then have the voltage between one of the conductors and the neutral plane. The correction factor for pressure and temperature is 0.97, and using the effective value of the voltage. we finally arrive at

$$E_{eff} = 120000\,(\rho+0.07)\log_{10}\frac{2\,D}{\rho}$$

This formula is supposed to apply only to conductors $\frac{1}{4}$ in. in diameter and upward. We will, therefore, exclude from the following table the values referring to a rod $\frac{1}{8}$ in. in diameter. The corona voltages, according to Ryan's formula, are then

D	Diameter of conductor		
	0.25 in.	0.375 in.	0.50 in.
9 in.	50500	61200	71500
12 in.	53500	65000	76500
18 in.	57700	70300	83000

Comparing these results obtained by Professor Ryan's formula with the results obtained experimentally, it will be seen that for the rod 0.25-in. in diameter the calculated results are higher than the test values. For the 0.375-in. rod the calculated results are still high, but nearer to test values, while for the 0.50-in. rod the calculated results are lower than the test values.

Without making any attempt to reconcile the departures which have been observed from the published formulas and constants, we will proceed to describe some of the experiments which have shown that so many conditions are to be considered in studying this phenomenon, in connection with apparatus, that it is apparently hopeless to evolve any formula that will be broad enough to be given general application. All the tests were made with a grounded plate as one electrode. It seemed advisable to do this, as it so simplified the problem as compared with the double condenser formed by the plate, conductor and earth, if the plate were ungrounded. The plate used, as before stated, was about 70 in. by 30 in. However, no material variation in results was obtained when a 13-in. disk was substituted for this plate.

In order to obtain consistent results it is, of course, but necessary to know the voltage wave-form which is used in the experiments, as the corona depends on the maximum rather than the average effective voltage as shown by a voltmeter. An attempt was made to determine the voltage by a spark gap in parallel with the apparatus under test, but the results obtained were very variable, and the attempt was given up for the following reasons:

If the gap was located in the small dark room in which the experiments were performed, the ionization of the air, resulting from the brush discharges, would affect the striking distance considerably.

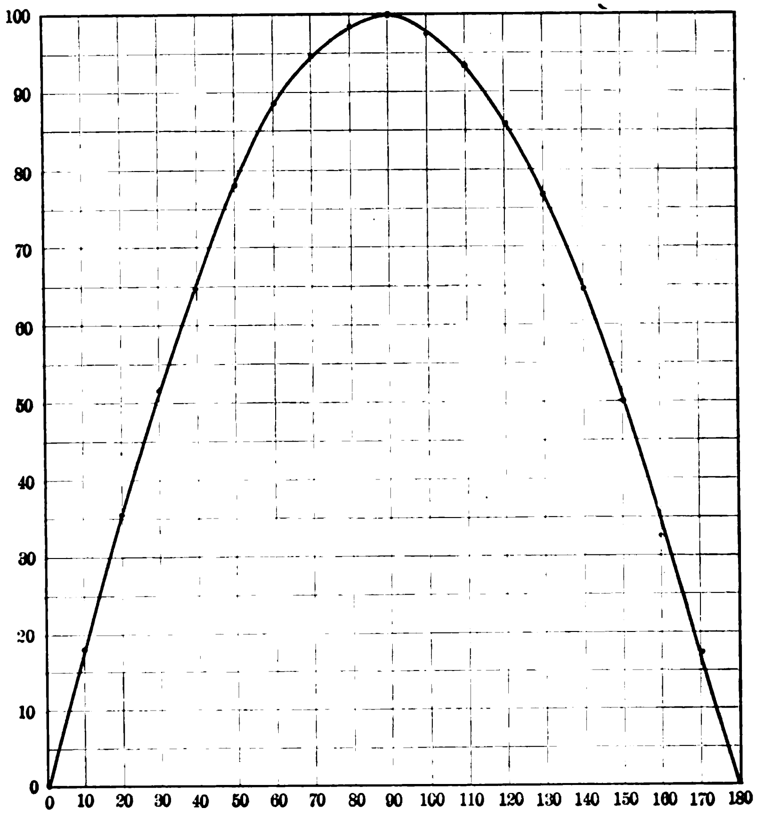

FIG. 4

If the gap was brought outside the dark room, then a source of error was introduced by the long leads required.

There are reasons to suppose that between the gap and the condenser under test some internal oscillations, which upset the results, are set up.

It was therefore thought better to take some oscillograms of electromotive force, reproduced in Figs. 4 and 5, to be sure that the wave-form was the sine wave that it was supposed to be. Fig. 4 represents the electromotive force across the terminals of the high-potential windings of the transformer used in the experiments. It was taken at no load and at 80,000 effective volts, with one terminal of the transformer grounded. The curves show a substantially perfect sine wave.

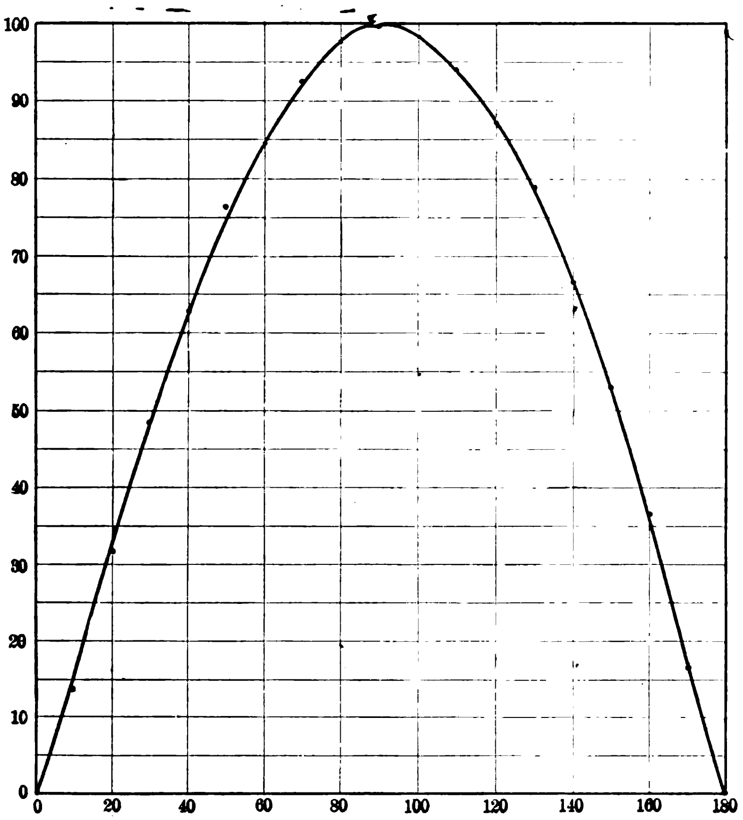

Fig. 5

Fig. 5 gives the shape of the wave of the electromotive force across the high-potential windings of the same transformer, with one terminal grounded at 60,000 volts, when the 0.25-in. rod is connected to the ungrounded terminal and the large iron plate is connected to the grounded terminal, the distance between the plate and the rod being 12 in. The change in the wave form is very small and the effective value is 0.698, the maximum value. It is known, therefore, that the tests were made with substantially sine waves.

Another very important point affecting results was found to be the condition of the surface of the conductor. Assuming, as we know to be the case, that the maximum potential gradient occurs at the surface of the conductor, and that the corona starts from the surface, it is obvious that any irregularity in the surface will have the effect of reducing the diameter of the conductor at that point. Consistent results can therefore only be obtained when the surface is free from any such rough spots or foreign material.

A rough metallic spot, constituting a point on the conductor, will naturally begin to glow at much lower voltage than the conductor itself on account of the much higher potential gradient at that point. These isolated points give a brilliant white light and they are easily distinguished from the regular corona and must be eliminated with great care, to obtain constant and consistent results.

More common, however, are spots of insulating material on the surface of the rod. These spots act quite differently from metallic spots; they also begin to glow, generally before the point of regular corona is reached, but they emit a blue, unsteady brush different in shape and color from the brilliant steady light given by a metallic point. A very peculiar characteristic of these brushes is the fact that they do not die out at the same voltage at which they are originally established, but to extinguish them the voltage must be lowered considerably below the original value.

If, for instance, we take the 0.375-in. rod parallel to the grounded plate, as shown in Fig. 2, and, in order to magnify the phenomenon, we slip a piece of rubber tube 3 in. long on the rod and then increase gradually the potential of the rod, we find that at 78,500 volts each edge of the rubber tube gives a blue, silent, unsteady brush, which increases in length and volume with increasing potential. If the voltage is lowered below 78,500 volts, the brushes do not die out until 68,000 volts are reached. To reëstablish the brushes after they have been extinguished 78.500 volts are again necessary.

In order to obtain consistent results, great care was taken during the tests to work with clean, uniform surfaces of conductors, which condition is not easily obtained. But the effect of insulation on the conductor appeared so peculiar that an investigation of this matter was started and very interesting results were gathered.

If in the test just mentioned, we raise the potential above 78,500 volts, the brushes at the edge of the rubber tube increase, as has been said, in length and volume until they span the whole distance between the rod and the plate. Increasing the potential still further, the color of the brushes changes from blue to purple and finally the spark jumps from the rod to the plate through the mass of one of the brushes. If no insulation were on the rod the break-down would have occurred at one of the ends of the rod, but the presence of the rubber tube has changed the conditions and has brought the weakest point of the system to the edge of the insulation. This phenomenon obtained with a piece of rubber tube can be reproduced by using any kind of insulating material on the surface of the rod. A thin coat of paraffin on the rod will produce the phenomenon as well as a glass or mica tube, a knot of varnished cambric tape, a rubber cork, a disc of sulphur, or the like.

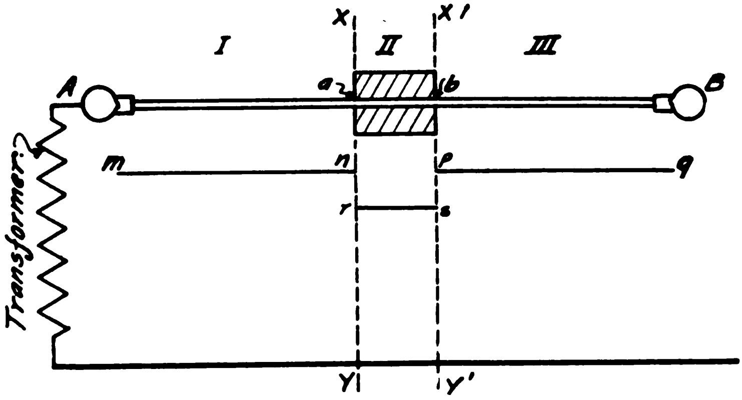

FIG. 6

Referring to Fig. 6, *A B* is a rod 0.25-in. in diameter, ended by two spheres 2 in. in diameter and brought 12 in. away from a plate. If we apply a difference of potential between the rod and plate, the system will break down at one of the spheres at 144,000 volts. If a rubber cork $\frac{3}{4}$ in. in diameter and 1 in. in length is slipped on the center of the rod, the center breaks down at one of the edges of the cork at 141,000 volts. If the cork is removed and replaced by varnished cambric tape wound on the rod, the system breaks down from the edge of the varnished cambric insulation at 135,000 volts. We see, therefore, that not only the edge of the insulation has become the weakest point of the system, but that the value of the breaking-down point has also been decreased. It would be superfluous to state the many tests performed on this point but they all agree and confirm the results already given.

An explanation of these results will be simple, we believe, if the disturbances in the field of electric forces, which take place on the introduction of the insulating material around the center of the rod *A B*, are investigated in the following way: Let us imagine the system of conductors and insulations in Fig. 6 divided up into three contiguous condensers I, II, III. If we attempt to draw any one of the equipotential surfaces of the system, we will see that in the condensers I and III, the sections of the equipotential surface are represented by the lines *m n* and *p q* at the same distance from *A B*. But in the condenser II, which has a material of high specific inductive capacity near the rod, the trace of the equipotential surface will be lower than *m n* and *p q*, say *r s*.

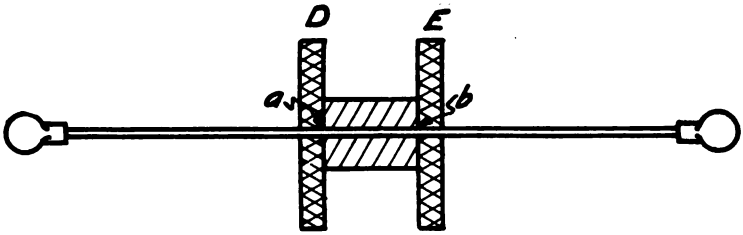

FIG. 7

In the vertical planes *X Y* and *X′ Y′*, the conditions of the field are very peculiar, inasmuch as the voltage of each point along these lines, considered as a part of condenser I, is different from the voltage of the same point considered as a part of condenser II. The result, we believe, therefore, shows the existence of a transverse stress along the lines *X Y* and *X′ Y′*, which causes the appearance of the brushes and the final breakdown.

If this is correct we should be able to stop the formation of brushes in *a b* by equalizing the potential along the planes *n r* and *p s* by metallic surfaces. If we slip on either side of the insulation two metallic disks (Fig. 7) having diameters as large, or larger, than the insulation, we should expect that we would eliminate the brushes *a b*. Tests show this to be the result. Two tinfoil disks 2 in. in diameter were put on the rod, as shown in Fig. 7. The edges of the insulation were entirely free from brush discharge and the condenser broke down at one of the spheres at 144,000 volts.

It is to be noted that although the metallic disks were nearer to the plate than the ends of the rod, still these ends remained the weakest point of the apparatus. But we should expect even more from the metallic disks. If we apply the same methods of reasoning used before, and we picture to ourselves the equipotential surfaces of the condenser, we should anticipate that the introduction of these disks on the rod should have the effect of relieving the stress from a certain length of the rod on each side of the disks. The test proves that this assumption is correct.

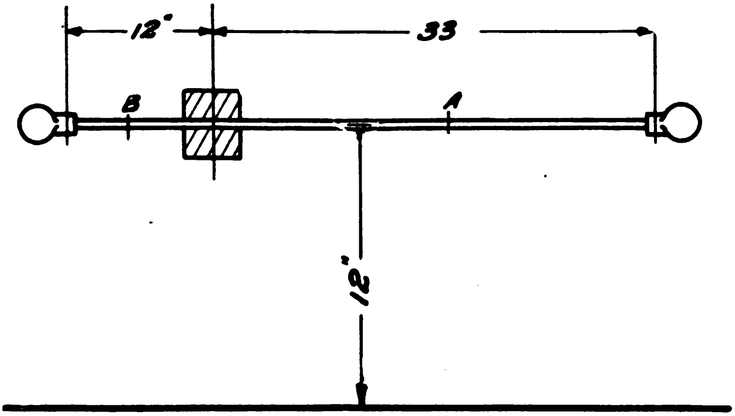

FIG. 8

We have seen that a rod, 0.25-in. in diameter and 45 in. long, parallel to a grounded plate, and 12 in. away from it, begins to glow at 57,000 volts. If we wrap tin-foil in the center of the rod, making a little cylinder 3 in. long and 1 in. in diameter, corona will appear in the middle of the two sections of the rod at 62,300 volts. Let us shift our tin-foil cylinder on the rod so that the two sections will be of different length. Then, as shown in Fig. 8, the middle of the longer section *A* glows at 59,250 volts, while the middle of the shorter section *B* does not glow until 76,500 volts are reached.

If we put on the same rod two cylinders of tin foil, spaced as shown in Fig. 9 the center of the middle section *B* glows at 69,750 volts, while the centers of the other two sections *A* and *C* glow simultaneously at 75,750 volts. This test shows conclusively that the metallic cylinders cast, so to speak, a shadow on the conductor on each side, protecting a certain length of it, and increasing, if properly spaced, the effective diameter of the rod.

Figs. 10, 11, 12 will serve as a summary of what we have seen regarding the influence of the condition of the surface of the conductors. Fig. 10 shows a 0.25-in. rod 88 in. long having a regularly distributed corona against the ground plate 12 in. from it. The photograph was taken at 85,000 volts. Fig. 11 shows the same rod in exactly the same conditions as before, at the same voltage, but a piece of varnished cambric tape is wrapped on the center of the rod and a strong brush is produced at this point. In Fig. 12 we have the same rod as before at the same voltage but with three tinfoil disks 2 in. in diameter equally spaced on the rod. The corona is very small and limited and very different from the one shown in Fig. 10.

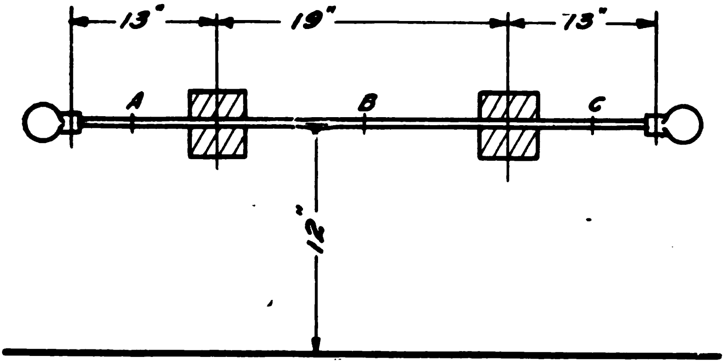

Fig. 9

A very interesting point was brought out in further study of the results obtained with the combinations shown in Figs. 8 and 9. When the voltages at which corona appeared on different portions of this apparatus are tabulated with reference to the free length of the conductor *A B* we find the following:

Free length of rod	Glowing point
45 in.	57,000 volts
31.5 in.	59,250 "
21 in.	62,300 "
16 in.	69,750 "
11.5 in.	75,750 "
10.5 in.	76,500 "

This shows that it takes an increasing voltage to establish corona the shorter the length of the rod. In other words, corona is not a fixed quantity for a given voltage and diameter of rod, unless the length of the rod is great and the diameter uniform. In order to thoroughly demonstrate this point, three rods ¼ in. in diameter were experimented with. The rods were of different length, all the other conditions of the test being identical. The arrangement was the one represented in Fig. 2 and the distance between the rod and the grounded plate was 12 in. The results of the test are as follows:

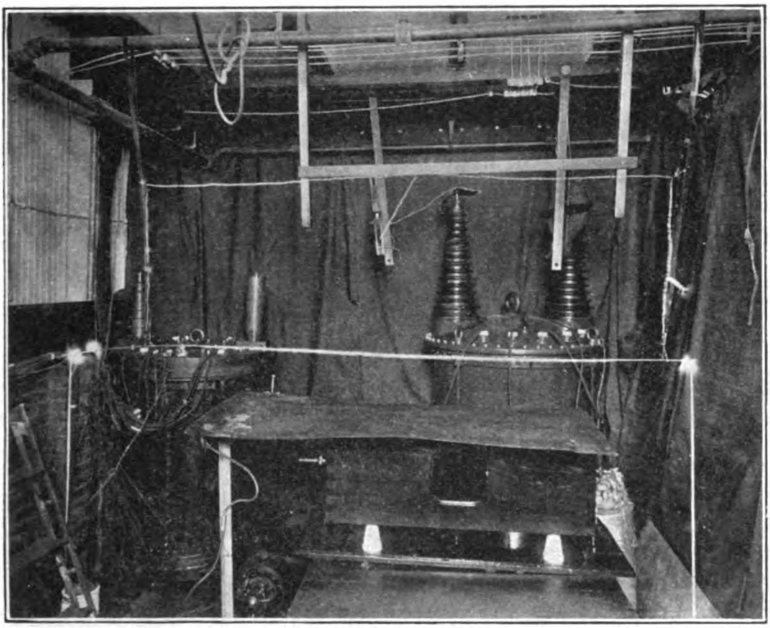

FIG. 10

Length of rod	Corona voltage
45 in.	57000 volts
23 in.	68000 "
12 in.	83500 "

These results are plotted in Fig. 13.

We see immediately that the values of this table differ from the corresponding values of the preceding table. We must realize, however, that the conditions of the test are somewhat different in the two cases and that the " suspension " of the rod might influence the results.

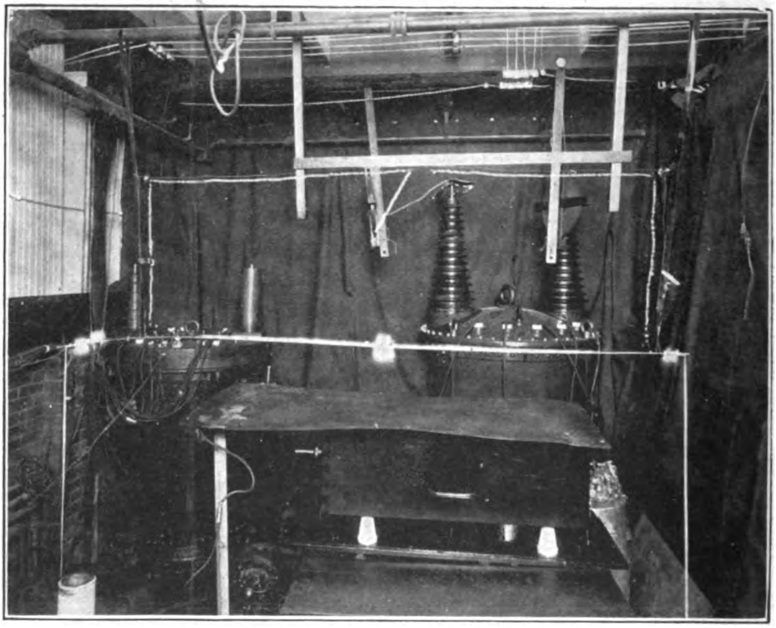

Fig. 11

Let us return to our apparatus as represented in Fig. 2, where the rod is suspended by copper wires and the suspension wires are connected together by the wire *C D*. Let us observe accurately what happens when we gradually raise the potential of the rod, which is 45 in. long, 0.25-in. in diameter and 12 in. away from the grounded plate.

At 57,000 volts the rod was dark.

At 58,000 volts the center of the rod glowed.

Theoretically we should expect that as soon as the critical voltage is reached corona should appear over the whole length of the rod. This is because we assume that the intensity of the field is constant all along the rod and the equipotential surfaces in the immediate neighborhood of the rod are cylinders practically concentric with it. This test shows, however, that the intensity of the field is not uniform throughout the length of the rod.

If we measure the exact location and length of corona at different voltages, and note its spreading with increasing potential, we will have an idea of the distribution of the field in the different points of the rod. At 58,000 volts the length of the glowing portion of the rod is 15 in. exactly in the center. At 80,000 volts its length becomes 33.5 in.; that is, the whole rod glows, except 6 in. near the suspension points. The system breaks down at 113,000 volts from one end of the rod, although even at this voltage the portion of the rod near the suspension wires remains dark.

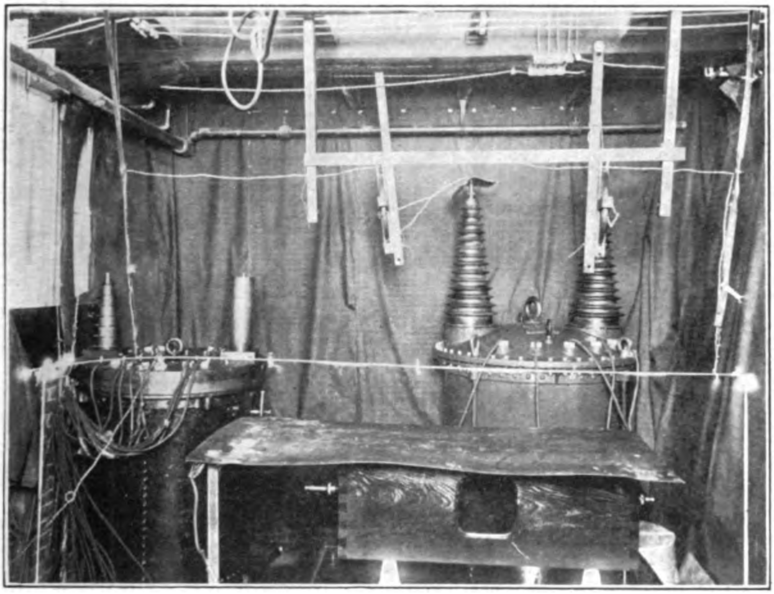

Fig. 12

Now let us repeat this test, but let us modify the suspension slightly. We eliminate the bridging wire *C D* and bring the high potential lead to *C*. The suspension wire *B D* is, therefore, connected to the rod only.

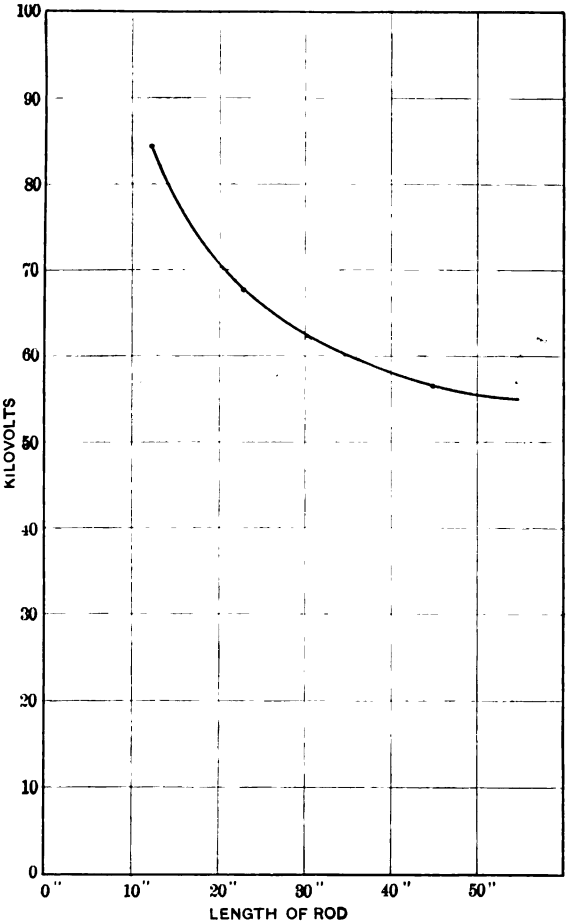

FIG. 13

At 54,000 volts the rod was dark.
At 55,000 " corona was 15 in. long in the center.
At 60,000 " " " 22 " "
At 80,000 " " " 33 " "
At 100,000 " " " 35 " "

At 112,000 volts the system breaks down from one of the ends to the plate.

We have changed the value of the voltage at which corona starts, although we have not changed practically the spreading of corona at high voltage. Finally let us remove the copper wire *B D* and replace it by silk tape. In this case the results are as follows:

At 50,000 volts the rod is dark.

At 51,000 volts, the portion of the rod near *B*, or near the silk tape suspension, glows for the length of 21 in. measured from *B*; in other words, the rod is divided into two sections, of which 24 in. near *A* are dark and 21 in. near *B* glow. Increasing the voltage, the corona approaches more and more, to the point *A*.

At 60,000 volts the corona is 33 in. long.

At 80,000 volts the corona is 40 in. long, or 5 in. near *A* remain dark.

At 90,000 volts the corona is 41 in. long, or 4 in. near *A* are dark.

At 105,000 volts the corona is again 41 in. long and at 112,000 volts a spark jumps from *A* to the plate.

The phenomenon is so delicate that it actually makes a difference whether the silk ribbon is tied in a knot around the rod or whether the rod is placed in a loop made by the ribbon. The knot gives a brush, while the loop originates a silent glowing on the rod near *B* before corona starts. The results obtained with the insulating suspension are not, generally speaking, so certain and constant as those obtained with the suspension represented in Fig. 2. This is the reason why the latter suspension has been chosen to perform comparative tests.

We must note that in all these experiments the " ends " of the rod do not affect the character of the phenomena. In fact similar results are obtained whether the rods are ended by spheres of large diameter or not. The curves in Fig. 14 represent the voltages and the corresponding lengths of corona in the three cases mentioned above. Curve 1 refers to the suspension shown in Fig. 2. Curve 2 refers to the same suspension without the bridging wire *C D*. Curve 3 refers to the silk-tape suspension.

A doubt may arise in connection with the results of these experiments, as one might suppose that the dimensions and the position of the grounded plate might affect the location and spreading of corona. This, however, is not the case. If the grounded plate is removed and the rod is left in the same place, forming a condenser with the floor, ceiling, walls, etc., of the room, the same results are obtained.

The voltage at which corona starts is naturally different, but the general appearance of the phenomenon is the same as before. If both ends of the rod are suspended by copper wires the center of the rod will glow first and the parts in the immediate neighborhood of the suspension points will not glow at the highest voltage. If one end of the rod is suspended by insulating material, this end will glow first and the corona gradually approach the excited end.

In conclusion, we have seen that the corona voltage is affected by many conditions which can hardly be taken care of in a formula. We have shown the influence of the following:

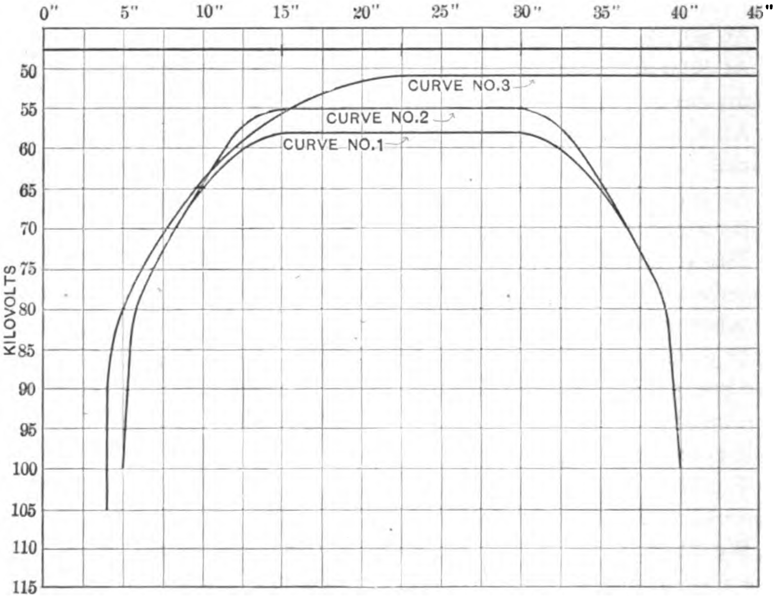

FIG. 14

1. Grounding the plate.
2. Wave form.
3. Conditions of surface, and effect of insulating and metallic disks.
4. Length of rod.
5. Suspension and consequent localizations and spreading of corona.

Before we leave this apparatus—a cylindrical conductor parallel to a plate—we might attempt to check, in a general way, the theoretical law which gives the corona voltage as a function of the diameter of the rod and its distance from the plate. If we take a rod of radius ρ' at a distance D' from the plate, and another rod of radius ρ'' at a distance D'' from the plate, the two rods ought to glow at the same voltage, if

$$\rho' \frac{\log 2\,D'}{\rho'} = \rho'' \frac{\log 2\,D''}{\rho''}$$

Unfortunately the change in the distance required by small change in diameter is very large. For instance, if we take two rods, one 0.25 in. in diameter, and the other 0.375 in. in diameter, the distances for the same corona voltages are respectively 9 in. and 28 in. Similarly, if we compare a ⅜-in. rod and a 0.25 in. rod, the theoretical distances are respectively 6 in. and 31½ in.

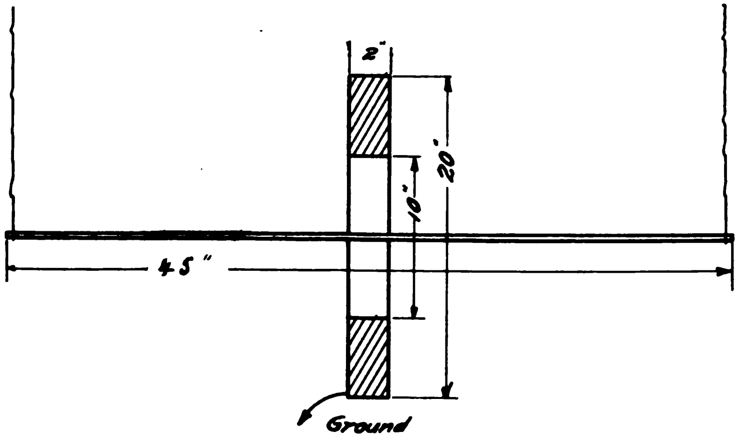

Fig. 15

For the reasons given in the foregoing, the tests to check this law proved to be erratic, as might be expected, but in general the tests show that a small rod at a comparatively great distance from the plate requires a higher voltage than a large rod at a correspondingly small distance from the plate. However, on account of the great difference in distances, it is almost impossible to reproduce exactly the same conditions of test in both cases, and, from what we have seen, the behavior of the electric field is so sensitive that we should not be surprised at the apparent inconsistency between theory and test.

The second type of condenser on which experiments were performed is illustrated in Fig. 15. Different rods 45 in. long, suspended at both ends by copper wires, were located in the center of a metallic disc. The dimensions of the ring are 10 in. inside diameter, 20 in. outside diameter and 2 in. long. The disk and the portion of the rod covered by it constitute a condenser whose theory we will briefly recall.

Fig. 16 represents a condenser of this type, C being the inside conductor of radius ρ'', G being the outside cylinder of radius ρ'. The lines of force of such a condenser are along the radii, and the cross sections of the equipotential surfaces are circumferences concentric with the plates. If we wish to find the potential of a point P at a distance m from the center we can imagine the equipotential surface passing through P materialized and metallic, as we did before.

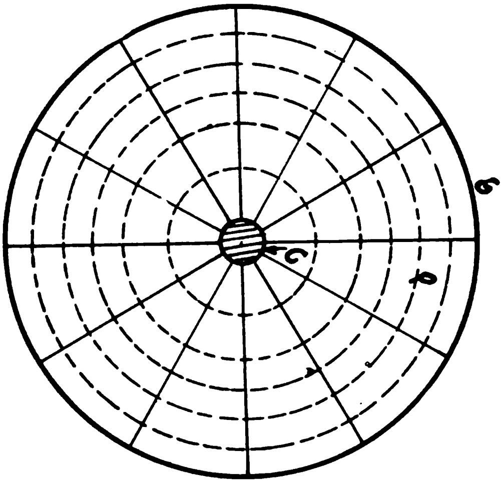

FIG. 16

Now the condenser made by the conductor C and the cylinder G is equivalent to two condensers in series, one from the conductor C to the equipotential surface P, the other from this surface to the cylinder G. If we call C the capacity between the conductor C and the cylinder G, C' the capacity between the equipotential surface P and the cylinder G, zero the potential of G, E the potential of C, E' the potential of P, we have

$$E' = \frac{C}{C'} E$$

$$\text{But } C = \frac{1}{2 \log \frac{\rho'}{\rho}} \text{ per unit length}$$

$$C' = \frac{1}{2 \log_n \frac{\rho'}{m}} \text{ per unit length}$$

Therefore:

$$E' = \frac{\log_n \frac{\rho'}{m}}{\log_n \frac{\rho'}{\rho}}$$

The potential gradient at P is

$$\frac{dE}{dm} = \kappa = \frac{0.434\, E}{m \log_{10} \frac{\rho'}{m}}$$

It is evident that the maximum potential gradient occurs when $m = \rho$, and is given by

$$\kappa_{max} = \frac{.434\, E}{\rho \log_{10} \frac{\rho'}{\rho}}$$

and the effective voltage at which corona will appear on the inside conductor is, in volts

$$E_{eff} = 160000\, \rho \log_{10} \frac{\rho'}{\rho}$$

If we apply this formula to the case of Fig. 15 for $\rho' = 5$ in. and for diameters of rods $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in., we have

Radius of conductor	Corona voltage
0.0625 in.	19000
0.125 in.	32000
0.187 in.	42600
0.250 in.	52000

In attempting to check these calculations with the apparatus shown in Fig. 15, the metallic cylinder was grounded and the rod connected to one of the terminals of the testing transformer, whose other terminal was grounded. The rod was 45 in. long and the cylinder 2 in. long, the latter being located in the center of the rod. The following results were obtained:

Radius of conductor	Corona voltage
0.0625 in.	26500
0.125 in.	40500
0.187 in.	52000
0.250 in.	62000

The tested values are again higher than the calculated values, but their difference is not constant. The discrepancies between tests and theories are undoubtedly explained by the fact that the formula applies to cylinders of indefinite length, whereas one cylinder in this case was very short and consequently the disturbing influences of the ends of the cylinder were proportionately very great.

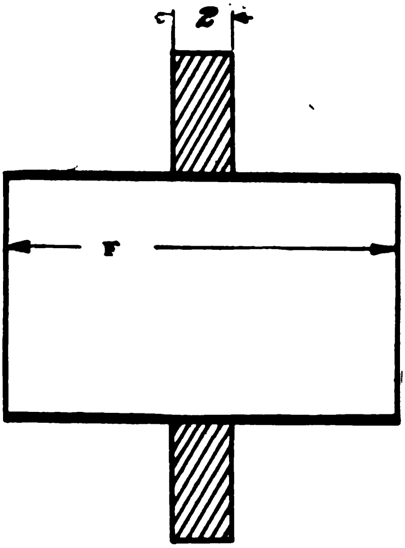

Fig. 17

Just how the length of the outside ring influences the results can be easily seen from the further tests made with apparatus as shown in Fig. 17. Metallic tubes of different lengths were inserted and supported by the cylinder previously used, and the following results were obtained with different lengths *F*:

Radius of rod	2 in. long	6 in. long	18 in. long
0.0625 in.	26500	25200	24000
0.125 in.	40500	38500	36500
0.187 in.	52000	48500	47500
0.250 in.	62000	——	54500

The longer the cylinder the lower is the corona voltage, which shows a more uniformly distributed field in the center of the apparatus; that is, the longer the cylinder the nearer we approach the theoretical results.

On the other hand, with the arrangement shown in Fig. 15, if the length of the rod is decreased, the voltage at which corona appears is increased, as shown by the following table:

Length of rod	Corona voltage
45 in.	40500
23 in.	41500
12 in.	44000

We obtain identical results if instead of using shorter rods, we shift the suspension wires nearer together so that the free lengths of the rod between the suspension points are respectively 45 in., 24 in., and 12 in. We see here again, as in the other type of condenser, the protecting influence of the suspension wires, which relieves the stress for a considerable length on the surface of the rod.

We should expect also to find that the cross-section of the ring has a pronounced influence on the results. If we take a pipe 1 in. in diameter, bend it in a ring 10 in. in diameter, pass through its center rods 45 in. long and of varying diameters, we then obtain the following results:

Radius of rod	Corona voltage
0.0625 in.	29600
0.125 in.	45000
0.187 in.	58000

The corona voltage has been increased considerably. It should be borne in mind, however, that we have not only changed the cross-section of the ring, but we have also decreased its length, the pipe used being only 1 in. in diameter.

The results of all these tests show that conditions existing in the field between the ring and the rod are very different from those assumed in our theory. The lines of force have commonly been thought of as perpendicular to the surfaces of the outside cylinder and uniformly distributed along its length. Evidently this cannot be the case when the length of the cylinder is short. The density of the field is a maximum in the central part of the rod and decreases in intensity towards the ends. This can be clearly shown by observing the fact that when the rod is excited from both ends the middle begins to glow at very much lower voltage than is required to distribute this glow upon the entire length of the rod. In fact, with the proper combination of apparatus, the voltage applied can be quite accurately determined by the length of the rod that glows. The following results were obtained by again using a 0.25-in. rod in the apparatus shown in Fig. 15.

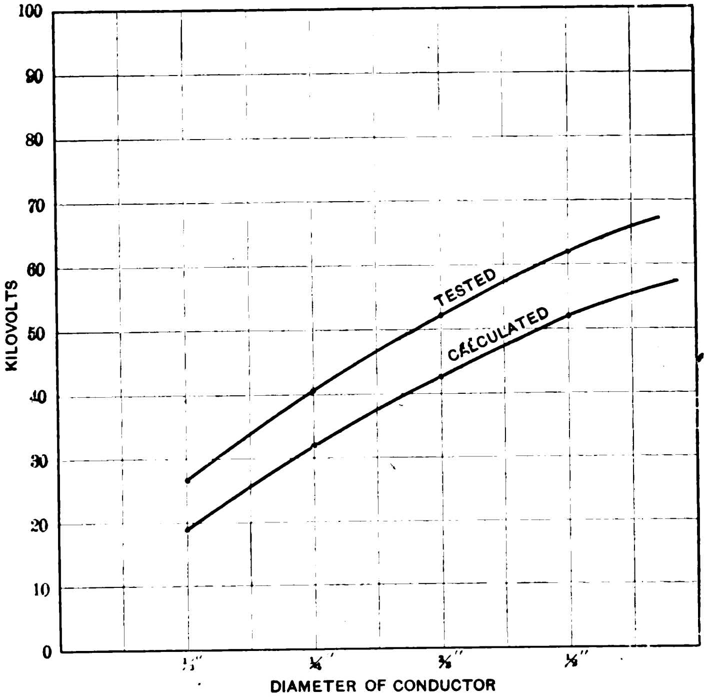

Fig. 18

At 40,000 volts the rod was dark.

At 40,500 the corona appeared in the center under the ring but the glowing portion was shorter than 2 in., which is the length of the outside cylinder.

At 45,000 volts the corona was 7 in. long in the center of the rod; protruding 2.8 in. on each side of the ring.

At 50,000 volts corona was 10 in. long
At 55,000 " " " 15 in. "
At 60,000 " " " 16 in. "
At 65,000 " " " 23 in. "
At 70,000 " " " 26 in. "

At 75,000 volts the apparatus broke down from the rod to the ring. Then at 40,500 volts the intensity of the field was not uniform under the cylinder, but was a maximum in the exact center of the rod. At 45,000 volts the critical value was reached over a portion of the rod much longer than the cylinder itself.

If we observe the glowing part of the rod at 70,000 volts, we will notice that its apparent diameter is constant for about 11 in. in the center, then it decreases gradually toward each end. But at comparatively large distances from the ring and at high potential, the surrounding bodies may have considerable disturbing influence on the glowing of the rod. If we change our suspension, using some insulating material at one end, or if we modify the conditions of the ends of the rod by using spheres of large diameter, the results are not affected, and the potential at which corona appears and the positions of corona on the conductor, are unaltered.

On the other hand, the effect of insulation and metallic sleeves on the conductor is the same as in the case of a rod against a plate. If we tie a piece of varnished cambric tape in the center of the 0.25-in. rod shown in Fig. 14, brushes will appear at the edges of the knot at 30,700 volts and the apparatus will break down at 40,500 volts from the insulation to the ring.

If we shift the knot of insulating tape at a distance of 3 in. from the edge of the ring, corona will appear on the conductor under the disk at the usual voltage—40,500 volts. But at 33,000 volts a brush has appeared at the edge of the insulating material facing the ring. Increasing the potential, the brush increases in strength, and at 45,000 volts a spark jumps from the insulation to the ring.

Let us shift the insulation knot 6 in. away from the edges of the ring. A brush will appear simultaneously with corona at 40,500 volts, and at 64,000 volts the system will break down again from the insulation to the ring. If we shift the varnished cambric tape still further away from the ring, say 12 in., the brush starts at 41,000 volts, but, in this case, the apparatus breaks down from the center of the rod to the ring at 75,000 volts. This is the voltage at which the system would have broken down if we had had no insulation on the rod.

It was necessary to remove the knot of varnished cambric 12 in. away from the ring to counteract the effect of insulation on the surface of the conductor. The breaking-down point is lowered considerably by the presence of the varnished cambric, and the remarkable short-circuiting effect of the brush caused the spark to strike through a much longer distance than the shortest path between the two plates of the condenser.

Metallic sleeves, we have seen, have the opposite effect. If two brass sleeves 0.5 in. outside diameter and 1 in. long are placed on the rod near its suspension points, the center point of the rod glows at 40,500 volts. If we shift the two brass cylinders nearer together so that each one is 12 in. away from the ring, the rod will glow again at 40,500 volts. If we bring the brass cylinders 3 in. away from the edge of the ring, corona will appear in the center of the rod at 41,500 volts. When the brass cylinders are placed 1 in. away from the edges of the ring the center of the rod begins to glow at 47,500 volts. If we bring the two brass cylinders still nearer, so that they are 2 in. apart, corona will appear only at 50,000 volts. The presence of the two metallic sleeves, therefore, does increase the apparent diameter of the rod, as far as corona is concerned, for a considerable distance on either side of the disc. In the last test the corona voltage was 50,000 instead of 40,500, which is equivalent to increasing the diameter of the rod from 0.25 in. to 0.375 in.

From all these experiments we can draw the general conclusion that the voltage at which corona appears in apparatus of limited dimensions, not only depends on the dimensions of the apparatus itself and the mutual action of the different parts, but is also a complex function of several quantities and conditions. Therefore, the formula which takes into consideration only the principal dimensions of the condenser between which the electric stress exists could not give correct results.

Before closing, we wish to say a few words with reference to corona as it exists under oil. We have often heard it said that the use of oil eliminates corona, but such is not the case in our opinion. There are some distinct differences in the manifestation of corona in air and in oil, but, so far as our present rather limited experimentation goes, we believe there is no essential difference in this manifestation in the two materials.

If we submerge two needles 12 in. apart in oil, and raise the difference of potential between them, there is no noticeable glow given off up to 100,000 volts, but with 1000 volts more, the glowing is very perceptible in the shape of a small steady brush, noiseless and green in color. We have here, then, not only a corona, but the same characteristic that is found in air corona; namely, that a very slight difference exists between the voltage at which there is no corona and that at which it appears.

If we raise the potential still further, the brushes increase in size and eventually touch each other and soon after cause a disruption of the oil. If the needles, instead of being 12 in. apart, are only 6 in. apart, the corona will be established at about 78,000 volts; if the needles are 3 in. apart, the corona will start at about 72,000 volts.

If before breakdown takes place, we decrease the difference of potential between the needles, the corona will disappear at the same voltage at which it started. Furthermore, the oil that is in the gap is set in violent motion, which is maintained so long as a stress exists. Analogous results can be obtained by using the needle opposed to the plate; that is, at a certain voltage the point will emit a steady luminous brush, which is similar to the brushes obtained in air.

Experiments were made on a condenser consisting of a cylindrical conductor and a plate under oil, as follows: A wire 0.02 in. in diameter and 15 in. long was stretched between two brass supports and a plate was placed 6.5 in. from the wire and parallel to it. One terminal of the transformer was connected to the wire and the other to the plate, and all were submerged in oil. At 49,000 volts everything was dark, at 50,000 volts the small wire glowed; when the potential was raised, the glow became more and more pronounced. The thickness of the corona appeared to be considerably more than in air and was more unsteady.

If, instead of 0.02 in. wire, we use 0.04 in. wire, the corona will not appear until 60,000 volts. In this case, the corona is made up of a large number of contiguous and unsteady brushes which cover the whole length of the wire. Using a wire 0.05 in. in diameter under the same condition, corona does not appear until 80,000 volts. In this case we obtain no regular glow, but very unsteady distinct brushes that shift their position along the wire. If we use 0.125-in. wire, the brush will appear at about 100,000 volts, and if we raise the potential, the brush will appear and disappear again irregularly; that is, we have an intermittent luminous phenomenon, which represents more of an interrupted arc then the regular corona. In explanation of this phenomenon, we would suggest that the very violent movement of oil under such dielectric strains may account for the unsteady nature of the corona at these higher potentials. It would seem, therefore, that the larger the diameter of the wire, and, consequently, the higher the voltage required for corona, the more the phenomenon under oil differs from phenomenon in air.

With our present knowledge, the comparison of values between corona voltage in air and under oil is very difficult and unsatisfactory. Under oil it is only with wires of small diameter that the corona voltage is sufficiently abrupt and constant to be measured consistently, while in air it is the small wires with which it is difficult to get consistent results. Such small wires in air depart markedly from the law that expresses the corona phenomenon on larger wires. The larger wires under oil, as we have said, give very unsteady and therefore, unsatisfactory results.

Similar tests were tried with wires located in the center of a 10-in. cylinder under oil, but the same conditions were met with. With wires above 0.125 in. in diameter, the point at which the corona started under oil is very uncertain and the luminous phenomenon is intermittent or irregular. Distances between wires and plates up to 4 ft. and potentials up to 400,000 volts were used, but the appearance of the phenomenon was always irregular.

Conclusions. We have selected in the foregoing, only a few of the interesting experiments in an incomplete investigation. We trust however that they will be sufficient to stimulate other investigators in this largely unexplored field.

Commercial transformers are now being extensively built to use for voltages where these complex laws of the corona must be generally, if not exactly, known, if their design is to be correctly worked out.

Of course it has been generally appreciated for some years that corona discharges must be avoided, even more in transformers than on the transmission line to which they are connected. When in transformer design only the simple law of the diameter of the conductor and the corresponding corona voltage are considered, and the effect of such factors as the length of the conductor, changes in its diameter and the solid insulation necessary on parts of the conductor are neglected, then these experiments show that it is not surprising that designs apparently similar, have given very different results in service.

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POWER REQUIREMENTS FOR ROLLING HIGH-CARBON STEEL OF SMALL SECTION

BY BRENT WILEY

The tests* in this paper were taken from a 9-in. merchant mill, a plan of which is shown in Fig. 1. The mill consists of seven stands of three-high rolls and one finishing stand of two-high rolls driven by a two-speed two-phase, 60-cycle, 2200-volt induction motor of squirrel-cage rotor construction, connected to the mill by means of a 42-in. three-ply belt. The ratings of the motor are 600 h. p. at 600 rev. per min. (synchronous speed) and 450 h. p. 450 rev. per min. The pulley reduction gives a mill-speed of one-half these values.

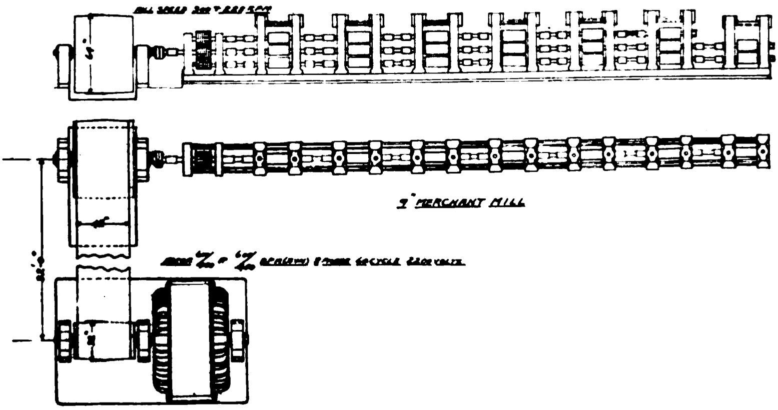

FIG. 1.—General arrangement of mill.

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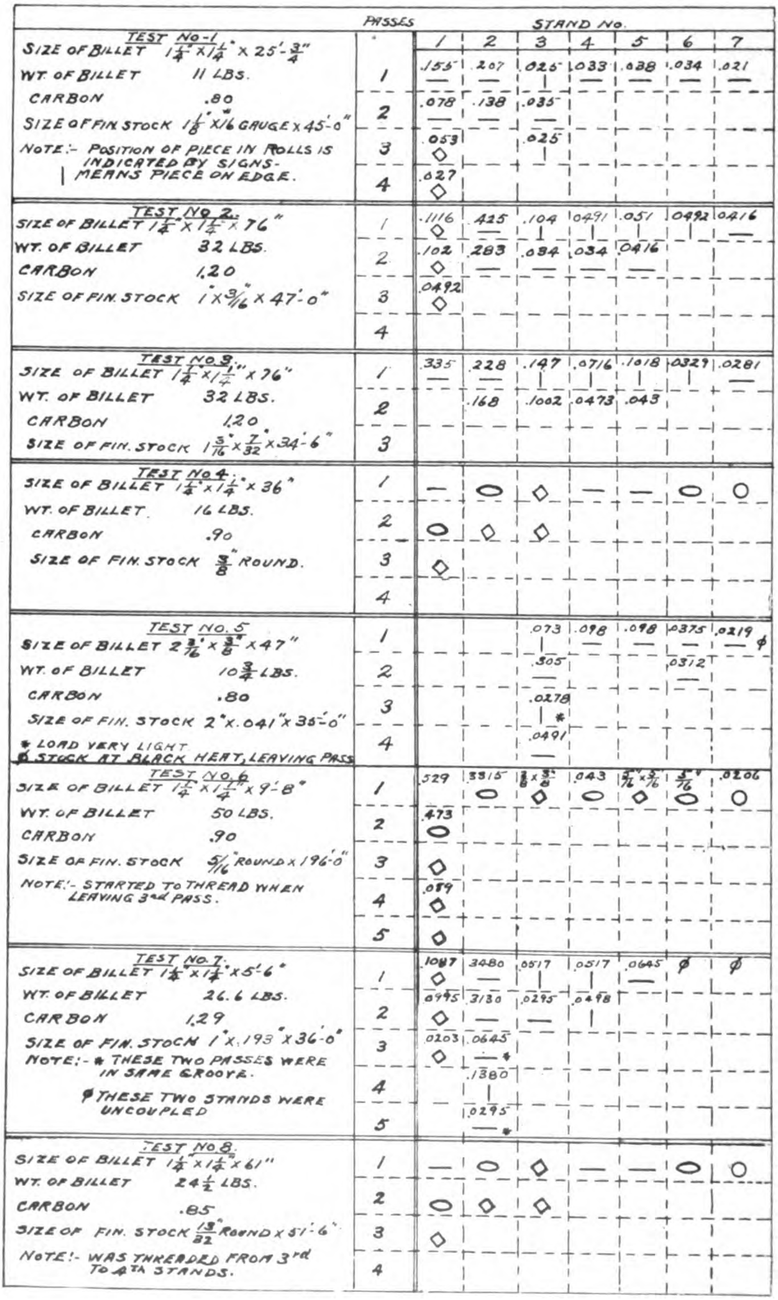
* The tests referred to in this paper were conducted under the supervision of C. J. Russell, through whose kindness they are presented in this form.



	PASSES	STAND NO. 1	2	3	4	5	6	7
TEST NO-1 SIZE OF BILLET 1¼" X 1¼" X 25'-¾" WT. OF BILLET 11 LBS. CARBON .80 SIZE OF FIN STOCK 1⅛" X 16 GAUGE X 45'-0" NOTE:- POSITION OF PIECE IN ROLLS IS INDICATED BY SIGNS- | MEANS PIECE ON EDGE.	1	.155 —	.207 —	.025 |	.033 —	.038 —	.034 —	.021 —
	2	.078 —	.138 —	.035 —				
	3	.053 ◇		.025 |				
	4	.027 ◇						
TEST NO 2. SIZE OF BILLET 1¼" X 1¼" X 76" WT. OF BILLET 32 LBS. CARBON 1.20 SIZE OF FIN. STOCK 1" X 3/16" X 47'-0"	1	.1116 ◇	.425 —	.104 |	.0491 |	.051 |	.0492 |	.0416 —
	2	.102 ◇	.283 —	.034 —	.034 —	.0416 —		
	3	.0492 ◇						
	4							
TEST NO 3. SIZE OF BILLET 1¼" X 1¼" X 76" WT. OF BILLET 32 LBS. CARBON 1.20 SIZE OF FIN. STOCK 1 3/16" X 7/32" X 34'-6"	1	.335 —	.228 —	.147 |	.0716 |	.1018 |	.0329 |	.0281 —
	2		.168	.1002	.0473	.043		
	3							
TEST NO 4. SIZE OF BILLET 1¼" X 1¼" X 36" WT. OF BILLET 16 LBS. CARBON .90 SIZE OF FIN. STOCK ⅜" ROUND.	1	—	⬭	◇	—	—	⬭	○
	2	⬭	◇	◇				
	3	◇						
	4							
TEST NO. 5 SIZE OF BILLET 2 3/16" X ⅜" X 47" WT. OF BILLET 10¾ LBS. CARBON .80 SIZE OF FIN. STOCK 2" X .041" X 35'-0" * LOAD VERY LIGHT ϕ STOCK AT BLACK HEAT, LEAVING PASS	1			.073 |	.098 —	.098 —	.0375 —	.0219 — ϕ
	2			.305 —			.0312 —	
	3			.0278 | *				
	4			.0491 —				
TEST NO. 6 SIZE OF BILLET 1¼" X 1¼" X 9'-8" WT. OF BILLET 50 LBS. CARBON .90 SIZE OF FIN. STOCK 5/16" ROUND X 196'-0" NOTE:- STARTED TO THREAD WHEN LEAVING 3rd PASS.	1	.529	.3315 ⬭	⅜" X ⅜" ◇	.043 ⬭	5/16" X 5/16" ◇	5/16" ⬭	.0206 ○
	2	.473 ⬭						
	3	◇						
	4	.089 ◇						
	5	◇						
TEST NO. 7. SIZE OF BILLET 1¼" X 1¼" X 5'-6" WT. OF BILLET 26.6 LBS. CARBON 1.29 SIZE OF FIN. STOCK 1" X .193" X 36'-0" NOTE:- * THESE TWO PASSES WERE IN SAME GROOVE. ϕ THESE TWO STANDS WERE UNCOUPLED	1	.1087 ◇	.3480 —	.0517 |	.0517 |	.0645 —	ϕ	ϕ
	2	.0995 ◇	.3130 —	.0295 —	.0498 |			
	3	.0203 ◇	.0645 — *					
	4		.1380 |					
	5		.0295 — *					
TEST NO 8. SIZE OF BILLET 1¼" X 1¼" X 61" WT. OF BILLET 24½ LBS. CARBON .85 SIZE OF FIN. STOCK 13/32" ROUND X 51'-6" NOTE:- WAS THREADED FROM 3rd TO 4th STANDS.	1	—	⬭	◇	—	—	⬭	○
	2	⬭	◇	◇				
	3	◇						
	4							

Table showing data for the eight sets of curves.

The product of this mill is high carbon steel of comparatively small section, test data being given for steel ranging from 0.80 to 1.29 carbon and of section ranging from $1\frac{3}{16}$ in. by $\frac{1}{32}$ in. to $\frac{5}{16}$ in. round. Originally the intention was to run the mill on the slow speed for the larger sections and on the high speed for the small rounds and very thin flats, but on testing the high speed operation it was found that special provisions would have to be made for handling the stock as it was being rolled, including the use of repeaters for the finishing stands. These plans have not been fully developed and all material is being rolled on the slow speed. The results obtained under these conditions are most gratifying, as a comparison with a steam-engine-driven mill of the same general design but of five stands of rolls shows that the capacity of the latter mill is exceeded by that of the motor-driven mill by 35 per cent. This difference is partly due to the two additional stands of rolls, but chiefly

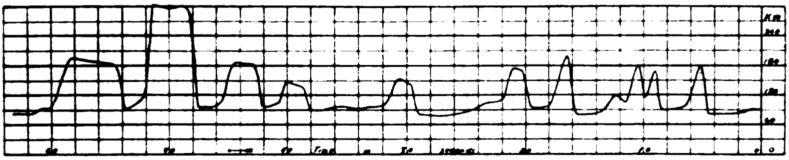


FIG. 2.—One piece in rolls, Test No. 1.

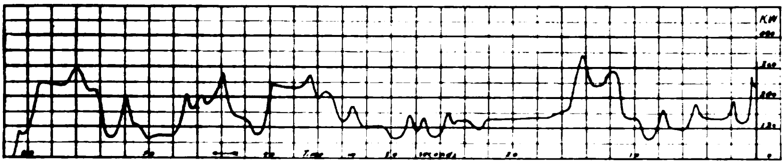


FIG. 3.—Rolling conditions, Test No. 1.

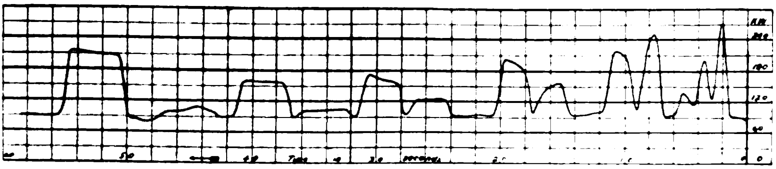


FIG. 4.—One piece in rolls, Test No. 2.

to the practically constant speed of the motor as the average speed of the engine is appreciably reduced by the heavy load conditions.

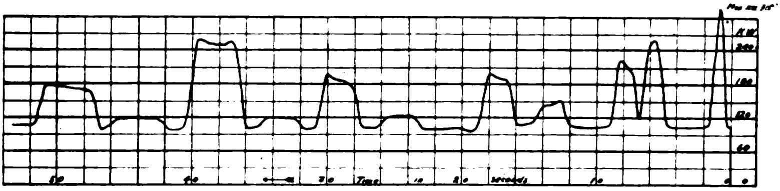


FIG. 5.—One piece in rolls, Test No. 3.

It will be seen that the areas of the sections at each pass are only approximate, but the relative values, which are of more importance, give a good idea of the operating conditions and work done.

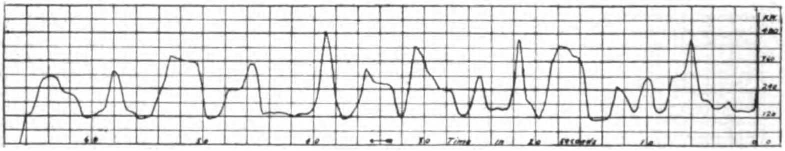


FIG. 6.—Rolling conditions, Test No. 3.

The recorded readings as shown by the series of curves were taken to obtain the power required per pass, the total power for one piece of stock, and the power requirements when the mill was in regular operation with several pieces of stock in the rolls at one time. These latter data were, however, not obtained for tests Nos. 2 and 6.

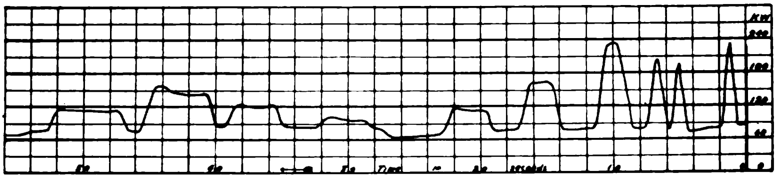


FIG. 7.—One piece in rolls, Test No. 4.

An all-day record was kept during test No. 7. The results give a good idea of the capacity and the average power requirements per ton of product.

Records observed from 6:55 a. m. to 3:49 p. m.

Size of stock rolled	1 in. by 0.193 in. by 36 ft-0 in.
Carbon	1.29
Size of billet	1.25 in. by 1.25 in. by 5 ft. 6 in.

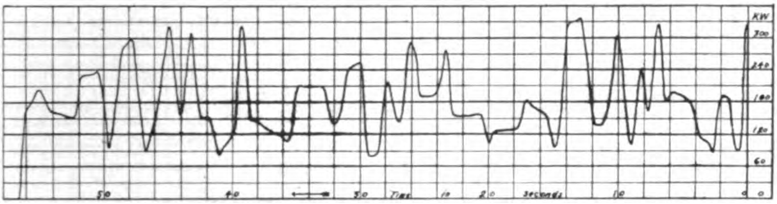


FIG. 8.—Rolling Conditions, Test No. 4.

Weight of billet	26.6 .lb
Number of billets rolled	1121
Total weight of billets	29,818 lb.
Actual operating time	408 min.

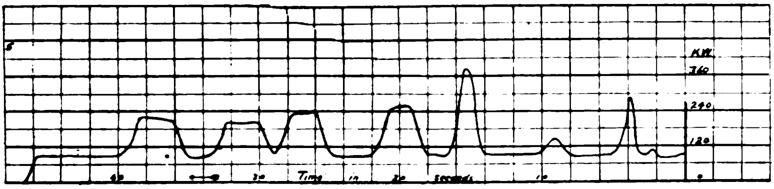


FIG. 9.—One piece in rolls, Test No. 5.

Time lost	126 min.
Total kilowatt-hours	1140
Kilowatt-hours friction load	408
Kilowatt-hours (including friction) per ton of metal rolled	71.2

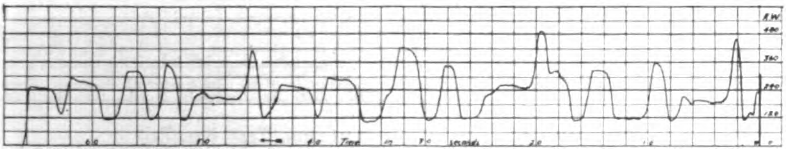


FIG. 10.—Rolling conditions, Test No. 5.

Recorded readings are shown in Figs. 12 and 13 were taken during the above run.

The fly-wheel effect of the system is practically limited to that of the rotor of the motor; this effect is comparatively small as the slip of the motor is but 3 per cent. at full load. The efficiency of the motor is, therefore, kept as high as possible. By referring to Fig. 6 (test No. 3), it will be seen that the peak-load conditions have a duration of approximately 6 sec; to equalize this load to the average power would require an excessively large fly-wheel on the mill-shaft, and the slip of the motor would have to be increased approximately three times the present value, thereby lowering the efficiency of the motor.

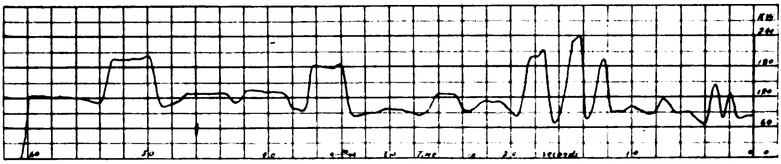


FIG. 11.—One piece in rolls, Test No. 6.

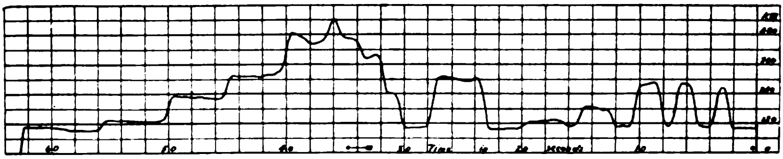


FIG. 12.—One piece in rolls, Test No. 7.

From the average working conditions as estimated from the various power curves for usual mill operation, it would require approximately a 15-ton fly-wheel 8 ft. in diameter, with a 10 per cent. drop in speed for 250 h. p. increase of load in order to lower appreciably the peak values of the load. The time and efficiency costs of this equalization do not warrant the use of a fly-wheel in the system.

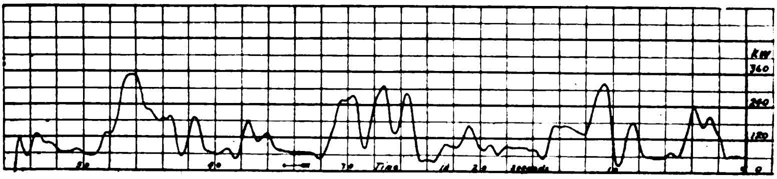


FIG. 13.—Rolling conditions, Test No. 7.

The friction load of the mill is somewhat high, this being due principally to the fact that it is necessary to keep the mill adjusted very closely. Every precaution is taken to keep the mill tight, which results in heavy pressures in the bearings.

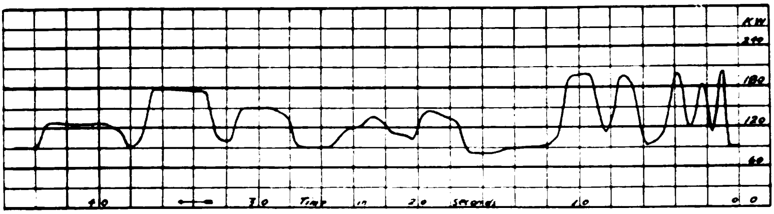


FIG. 14.—One piece in rolls, Test No. 8.

It is generally supposed that, due to its hardness, more power is required to roll the high-carbon steel than the ordinary mill steel, but at the same temperatures the energy required is

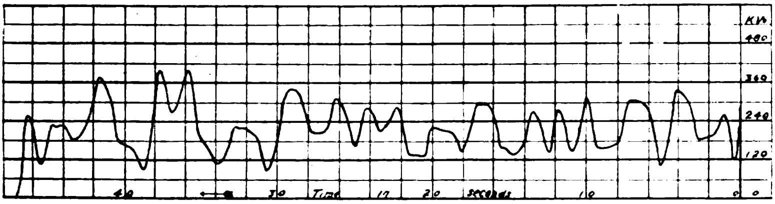


FIG. 15.—Rolling conditions, Test No. 8.

practically the same. Owing to the high percentage of carbon the harder steel billet must not be heated as hot as the milder steel, and it is therefore rolled at a lower temperature, the lighter sections being finished at a black heat.

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ELECTRIC-DRIVEN ROLLING MILLS

BY E. FRIEDLANDER

The first electric-driven steel rolling mill in the United States was installed about four years ago by the Carnegie Steel Company at their Edgar Thomson Works. Since then a number of other electric mill drives have been installed and run with entire success, a noteworthy example being found at the steel plant at Gary, Indiana.

The introduction of the electric drive has made it possible to clear up many points in regard to the power required for rolling different shapes of steel, and moreover, the roller, or operator, is able to see at a glance the work done by each pass. The electric roll drive has also taught us how to get the best relation among rotating masses, speed, time, and horse power. It has helped the roll designer to calibrate rolls in such a manner that the power characteristic for all the passes is uniform, thereby avoiding high power peaks, decreasing the size of the prime-mover, and reducing first cost and fuel consumption.

The watt-hour meter warns the roller of bearings or rolls becoming tight and hot, or that steel is causing excessive friction in the passes, often due to overfilling, cold steel or faulty calibration, thereby guarding against damage to the rolls and bearings. The meter indicates that lower heat, greater elongation and especially change of profile in different directions, increase the power required at the rolls much more rapidly than do chemical hardness, high tensile strength, or larger draughts. The meter also shows that it is not the higher percentage of carbon in steel which requires more power in rolling but the lower temperatures at which this steel has to be rolled, and also that an increase in width of the steel shape requires more power than a decrease in height. By means of the meter too, it can readily be seen that rolling " squares " and " rounds " takes per square inch displacement much less power than shapes with large peripheries and many flanges, as the latter cool off quickly and cause much friction in the rolls.

Tests on rail-mills have shown that the foot-pounds per square inch of displacement gradually increase the nearer the rail is to the finishing pass. A 75-lb. rail required 1100 ft-lb. at the first pass on the first " rougher. On the same stand in the seventh pass it required 3000 ft-lb., in the first pass on the second roughing rolls 4800 ft-lb., in the fifth pass 8150 ft-lb.; 9500 ft-lb. were required for the last or finishing pass. The large increase in foot-pounds is partly due to the greater density and rapid cooling of the steel, especially at the thinner flanges near the finishing pass. For this reason, the flanges are rolled out as late as possible. Whenever required, exact power consumption can be given for each phase of rolling.

The ideal motive power for rolls should drive them slowly when the steel enters and should drive the roll faster as the piece lengthens. The reciprocating engine will do just the reverse; namely, run very fast without load and slow down as the load increases, finally stopping if the load becomes too great.

The maximum torque of reciprocating engines is fixed by the size of the cylinders and the pressure; it cannot be increased no matter how much steam or gas is available. For this reason most mill engines are made very large and often run with only half load, causing high steam consumption per horse power, their most economical cut-off being at full load.

For this work the characteristics of the electric motor are much better. Even with double its full torque, the efficiency is good and the motor will not stop, but will take more and more current, finally becoming overheated and burning unless properly protected. If desirable, its speed changes from no load to full load can be made small. The current can also be limited to a certain maximum, without stopping the motor. in this manner preventing excessive strains and probably serious breakdowns.

Where high speeds are necessary, motors can be direct connected to rolls, increasing the energy of the rotating parts and at the same time decreasing the size of motor, the power required and the fuel consumption. Heavy reciprocating engines cannot run at such high speeds, and must be connected to the rolls by means of gears, ropes or belts.

To obtain accurate information as to the exact power requirements for rolling steel, indicator diagrams were taken on reciprocating engines doing similar work, but these in many instances were misleading. The work of rolling steel is very changeable and intermittent. Engines often run with light loads, but at short intervals have their valves wide open. This, together with the work done due to the energy of the rotating parts, should be carefully observed. Although it probably is not difficult to get the maximum torque required to decide on the normal capacity of the motor, the above-mentioned points must be considered, together with the length and number of pieces in the rolls, and also time-intervals between passes. To be on the safe side it is advisable to follow standard mill practice and make motors of ample size and strength, in order to stand the severe service and overloads without injury.

In mentioning fly-wheels, the writer had only three high non-reversible mills in mind. As the weight of rotating parts is much greater in large motors than in reciprocating engines, and the energy of the rotating parts increases as the square of the speed, it is obvious that even a small change in speed is of great importance. As tests have shown that rotating masses are sometimes not only of no use but that they often prove a drag on the motor, careful study of this feature has to be made in each case.

While the steel is being rolled, both the motor and the fly-wheel should furnish the power, but as soon as the steel leaves the rolls the motor should accelerate the rotating masses to the same speed before rolling. The time available and the number of revolutions will determine the size of the motor more than anything else.

It has been observed that on blooming and roughing mills, where the pieces are very short and the intervals long, rotating masses supply the largest part of energy during the rolling period and should therefore be large. The reverse takes place at the finishing passes, where pieces are long and follow each other rapidly. Heavy rotating masses would in this case be useless, and would even require larger motors for their quick acceleration.

Where one motor drives roughing and finishing rolls, curves should be plotted showing the number of pieces in the rolls at the same time, the length of passes and intervals, the power required for each pass, etc. With the help of such curves, the best relation between the sizes and speed of the motor and fly-wheel, radius of gyration, and slip of motor can be easily determined.

The total motive power required in a steel plant is changeable and fluctuates continuously, the average in many plants being often below one-fourth of the total horse power installed in motors. The electric-driven rolling mills will, however, demand considerably larger power-stations to take care of the large currents, especially when all the motors happen to be overloaded at one time, as for instance when rolling cold steel. It is very important to find out beforehand how much of this fluctuating load the power house may have to supply, assuming the worst conditions, as the shut-down of the electric power station for even a very short time, will stop the operation of a large number of machines and cause enormous losses. This is the one very objectionable feature of making such a great number of prime movers entirely dependent on one power station, and, therefore, some means should be taken to prevent this disturbance.

With steam engines and boilers the liability of a complete shutdown is not so great, but the delays and annnoyances caused by low steam-pressure are of daily occurrence in many plants. In such cases not only will all the steam-driven prime movers be unable to develop the required power, but also in trying to develop this power, they will use more and more steam, thus making it difficult to raise the steam pressure without increasing the number of boilers, or decreasing for a while the load and consequently the production.

The short, high-peaked current demands should be kept off the power station as much as possible and only the average current be supplied. The least number of units can then be kept running under nearly full load with the most economical fuel consumption and the least wear and tear of moving parts. As before mentioned, the average current consumption in a steel plant is always small in comparison with motor capacity, on account of the intermittent work and large amount of inertia of the rotating parts. By means of storage-batteries or fly-wheel sub-stations the occasional large demands for current can be taken off the station and supplied from these two sources, where it is stored up when the current demand is below the average.

The exchange of current from one motor to another, in connection with electric roll-drives, is often considerable and should not be overlooked.

With regard to the electric reversing mill, it is a fact that soon after its first appearance the use of reversing rolls became more general, especially in England and Germany. In those countries, small quantities of one kind and shape of material are rolled, and the cost of the large number of rolls required and the saving of time in changing rolls are probably the chief reasons for using the reversing mill, where many different sections can be worked with the same rolls. The absence of the heavy and troublesome lifting tables is also a welcome feature, especially when pieces rolled are very long.

The first installation in this country of an electric reversing mill, at the Illinois Steel Company's works at South Chicago, has given entire satisfaction from the start, and has demonstrated that the electric motor is much better adapted for this kind of work than the reciprocating engine. Although the first cost was high, its lower depreciation, better operation and lower cost of maintenance should justify its installation.

In a reversing mill the operator is able to draw steel slowly into the rolls and " speed up " while the piece lengthens, making a great advantage in rolling steel. In order to obtain perfect speed regulation, no use can be made of steam expansion, but admission continues during nearly full stroke. Even then much depends on the skill of the operator, who can subject the engine and the mill to very severe shocks and cause serious breakdowns if he is not careful. Reversing mills are therefore made heavy and strong.

If too much steam is admitted, it is difficult to prevent such large engines from racing without load. It is also wasteful, as both the time of actual rolling and the speed of the rolls are limited, most of the power being consumed in the rapid starting and stopping of the heavy rotating parts, without making any use of their fly-wheel energy.

With the use of electric motors in place of reciprocating engines, the problem of reversing rolls becomes much simpler and better, in regard to manipulation, fuel consumption, and cost of maintenance. Operation of electric-driven reversing mills is nearly automatic; no skilled operator is required and all danger to the motor and the mill is eliminated. The speed of acceleration is prearranged, and no matter how fast the operator moves his levers, the maximum current and the speed are limited.

Reversing is done with the least shocks in rolls and couplings and the danger of overstraining machinery is done away with. It is important to be able to reverse the motor just as rapidly as the engine. Special care should therefore be taken to have a motor-generator that will give large currents with very low excitation, and one that will be quickly magnetized and demagnetized.

It has been observed that only one-fourth of the power required at the reversing-roll motor is the average supplied from the power station. The large current demands are furnished by the motor-generator through the energy of the high-speed fly-wheel, and a considerable amount of current is sometimes sent back into the line.

As for all other mill work where power and speed variation are considerable, the direct-current motor, on account of its load and speed characteristics, is better adapted for driving rolls than the alternating-current motor. For reversible roll drives it is used exclusively.

There is no reason why the direct-current motor should give any more trouble than the direct-current generator at the power station. Four years' experience has shown that the wear of the commutator and the cost of maintenance amount to practically nothing. The transmission of large low-tension currents is much more serious, especially when tens of thousands of horsepower have to be supplied and the distance of the motors from the station is considerable.

The use of higher direct-current voltages in connection with large rolling mill motors should be satisfactory; but no doubt high-tension alternating-current transmission and induction motors direct on the line will be generally employed, especially in new installations. Where conditions demand it, the induction motor characteristics can now be made nearly similar to the compound-wound, direct-current motor. However, much of its simplicity and efficiency will be sacrificed in doing this.

Among some of the earlier disadvantages of the induction motor were: very large current required for starting under heavy load; one speed fixed by the number of poles and the tendency always to run at synchronous speed; low power-factor with light loads; small air gaps; impracticability of reversing large units; and inability to change speed to fly-wheel requirements.

In the design of the modern rolling-mill motor, most of these objectionable points have been remedied by different means such as wound rotors, the introduction of variable resistance, changing the number of poles, shifting the phases, slip-rings, etc.

Whether direct-current power stations and direct-current motors are used, or alternating-current stations are installed for high-tension transmission with alternating-current motors directly on the line or fed through transformers, or direct-current motors are supplied from an alternating-current station through converters, or motor-generators, batteries or fly-wheel substations, is a matter of detail. No doubt any one of these systems will give satisfaction if properly designed and installed.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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(*Subject to final revision for the Transactions.*)

ROLLING MILL MOTORS

BY E. W. YEARSLEY

Protection is extremely important in the steel mill where conditions are necessarily uncleanly, and electrical apparatus must work in the midst of dust, moisture, and gases. Large motors should be enclosed in solidly built tight compartments, ventilated by clean air if necessary, or should be of the totally enclosed type.

Considered economically the writer believes main motor drives to be superior to engine drives, even when power must be derived from a steam engine-driven generator plant fed by coal-fired boilers. Steam losses due to condensation and leaky valves and rings are surprisingly large, but usually escape definite measurement. Then in the usual rolling-mill engine, very little expansion is utilized, and it is not likely that attempts to refine such machines are satisfactory. Where water power or waste gas is available there is no question of the greater economy of electric drive.

The controlling apparatus for mill service is usually the weak part of the system; it is much less satisfactory than the motors. Mechanical strength and simplicity are the main points to be observed in designing this apparatus. Heavier and more mechanical switches and circuit-breakers, better protected and more durable rheostats, and more dependable automatic controlling devices, requiring less attention, are badly needed. This is a problem more difficult of solution than improvement of the motor, but no less necessary.

For large main-drive motors the advantage of continuous running at constant speed is so great that it would appear advisable to make the design of the mill suit the characteristics of the motor, and avoid the extra expense and complication of devices like the reversing drive. The tendency has been to build a machine and then to couple on a motor somewhere to drive it. This mistake, while not so frequent as formerly, is still made.

There seems to be no great difficulty in designing mills for continuous-running motors. By combining such motors with a suitable fly-wheel, it should be possible to keep the line load sufficiently uniform. This combination has not, in the writers opinion, received sufficient attention, possibly because of lack of knowledge of power and speed regulations of the rolling operation.

Tests of these characteristics will be comparatively easy on electric mills, so that data will rapidly become available for supplying the system with the proper inertia. In some installations the writer has seen the fly-wheel so badly proportioned as to be detrimental to the operation of the motor. Initial speeds should be carefully selected, especially when the drive is direct, and if possible a considerable speed regulation should be provided, so that the speed may be increased with increase in proficiency of the operators.

The importance of low armature inertia for reversing motors is now well recognized but designs could be improved by still further reduction in speed. The writer is decidedly against the use of high-speed motors for any kind of mill service and believes the extra cost of slow-speed machines well warranted.

Electric motors subject to excessive vibration communicated from the gearing and other parts of the machine should be protected by a flexible coupling.

For mill apparatus which must be handled directly, especially for direct-current apparatus, the writer favors a maximum of 250 volts. Safety of employes requires that with higher voltages special guards be provided to isolate the apparatus.

Alternating-current and direct-current motors and apparatus both have their advantages for steel mill installations. Local conditions must determine which is superior. Unless transmissions are too long, the writer favors a direct-current installation, especially if the plant has many machine tools. With an alternating-current system as few direct-current motors as possible should be used.

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ELECTROMOTIVE FORCE WAVE-SHAPE IN ALTERNATORS

BY COMFORT A. ADAMS

The method of connecting the shape of the flux distribution curve of a synchronous converter with the shape of its induced electromotive force wave, developed by the writer in his Atlantic City paper,* is here applied more specifically to the alternator, with an illustration taken from Mr. Bache-Wiig's Atlantic City paper on the " Application of Fractional Pitch Windings to Alternating-Current Generators ". Parts of the explanation of the *method* are reproduced in a somewhat modified and condensed form for the benefit of those who did not read the other paper.

The shape of the electromotive force wave of an alternator at no load is in general dependent upon the shape of the flux distribution curve and upon the arrangement of the armature conductors. But when the slots are large as compared with the air-gap, there is a pulsation of the flux in both magnitude and position,† which may materially alter the shape of the electromotive force wave. In the case of modern alternators with good inherent regulation, the air-gap is usually so long that these tooth pulsations are negligible; they will therefore not be considered here. The long gap and stiff field also tend to minimize the distortional effect of the armature magnetomotive force and to maintain a more nearly constant wave-shape at all loads.

With these reservations it will be assumed that a single conductor or a bundle of conductors placed in a single slot, will experience an electromotive force the wave-shape of which is the same as that of the flux distribution curve.

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* " Voltage Ratio in Synchronous Converters, with Special Reference to the Split Pole Converter." A. I. E. E. June, 1908.

† " Magnetic Pulsation in Alternators." Worrall. I. E. E. Jan. 1908.

The electromotive force of one phase of an alternator is ordinarily made up of several of these slot electromotive forces added together in their proper phase relation, the electromotive forces of two adjacent slots being displaced by an angle corresponding to the slot pitch. If each slot electromotive force were sinusoidal the addition could be readily accomplished, but as this is not usually the case, the problem is not quite so simple. The method here employed is as follows:

Analyze the flux distribution curve into its fundamental and its various harmonics.

Make a vector addition of the fundamentals of the proper slot electromotive forces to obtain the fundamental of the phase electromotive force.

Make a vector addition of the mth harmonic of the proper slot electromotive forces to obtain the mth harmonic of the phase electromotive force.

Add the phase fundamental to the several phase harmonics to obtain the complete phase electromotive force.

Unless it is desired actually to plot the resultant wave, the last step is not necessary, since for all purposes of calculation the harmonics are treated separately.

TYPES OF ARMATURE WINDING

In order properly to carry out the above-mentioned vector additions, it will be necessary to consider the possible relative locations of the coil-sides which go to make up a given phase of the winding.

For the present purpose alternator armature windings may be classified as follows:

a. According to the angular span of a single phase belt. In the ordinary three-phase alternator this is 60 degrees, and as the three-phase machine is so nearly exclusively employed at the present time, the following discussion will refer thereto unless otherwise specified.

b. According to the number of slots per pole. Although this quantity can have almost any value, the more common values are small multiples of the number of phases, and these common values will be here considered unless otherwise specified.

c. According to the "pitch," "span" or "throw" of the coils.

The coil pitch is usually equal to or less than the pole pitch. Fig. 1 shows a simple two-layer winding with a full-pitch winding, six slots in six. Fig. 2 shows the same winding except that the coil pitch is reduced to four slots in six, or 66⅔ per cent. In this two-layer type of winding the pitch may be any whole number of slots, without destroying the mechanical symmetry.

d. According to the number of coil sides per slot. The two-layer winding shown in Figs. 1 and 2 has two coil-sides per slot, but a somewhat equivalent winding may be made with one coil-side per slot, see Fig. 3. With this one-layer winding, however, mechanical symmetry demands a coil pitch which, when measured in slots, is odd. In Fig. 4 is shown a similar one-layer winding, but with nine slots per pole; here there is a dissymmetry of coil connection, in that the alternate groups of coils in a given phase contain numbers of coils differing by one. This will be found to hold in this type of winding whenever the number of slots per pole is odd, 9, 15, 21, etc.

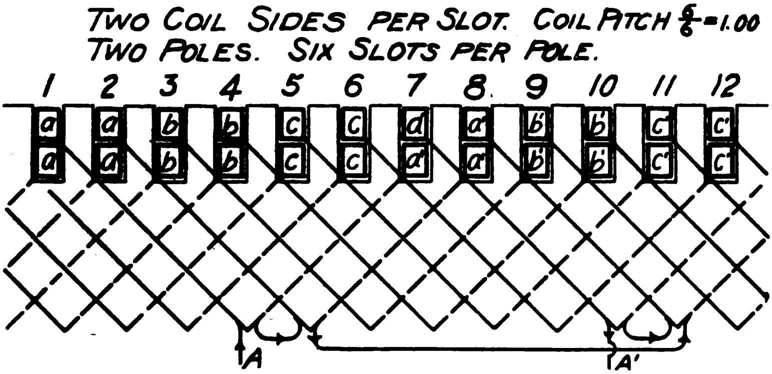
TWO COIL SIDES PER SLOT. COIL PITCH $\frac{6}{6}$=1.00
TWO POLES. SIX SLOTS PER POLE.
1
2
3
4
5
6
7
8
9
10
11
12
a
a
b
b
c
c
a'
a'
b'
b'
c'
c'
A
A'

FIG. 1

There are other very common types of alternator armature windings, but for the purpose in hand they are for the most part equivalent to those already described.

In each type of winding shown there are two groups of coils per phase per pair of poles, and these are shown connected together between the terminals, *A* and *A'*. In each case except that of Fig. 4 the two groups thus connected are exactly similar. Each group of coils is in turn made up of two similar groups of coil-sides or phase *belts*. In Fig. 1 one of these belts comprises the two coil-sides in the tops of slots No. 1 and No. 2, and the other includes the two coil-sides in the bottoms of slots No. 7 and No. 8. These two belts make up one of the similar coil-groups above referred to, the electromotive force of which has the same shape as that of the whole phase. In Fig. 1 the two belts in question are displaced by six slots or 180 degrees (electrical), and as they are connected in circuit opposition their electromotive forces are exactly in phase. Thus the electromotive force of one of these belts is a sample of the whole phase electromotive force.

In Fig. 2, however, the second belt (in the bottom of slots No. 4 and No. 5) is displaced from the first by only three slots, or 90 degrees, and the two belt electromotive forces differ in phase by 180 degrees — 90 degrees = 90 degrees, which is the pitch deficiency of the coils, measured in electrical degrees. In this case the electromotive force of the coil-group has the same shape as that of the whole phase-circuit, but in general not the same shape as that of a single belt.

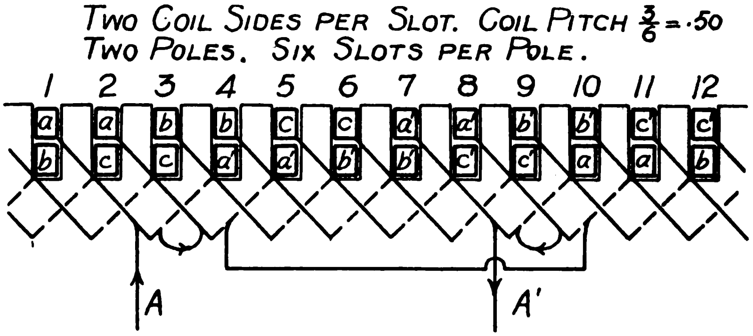
Two Coil Sides per Slot. Coil Pitch $\frac{3}{6}$ = .50
Two Poles. Six Slots per Pole.
1 2 3 4 5 6 7 8 9 10 11 12
a a b b c c a' a' b' b' c' c'
b c c a' a' b' b' c' c' a a b
A
A'

FIG. 2

In Fig. 3 the belt, which in Fig. 2 is distributed in the tops of slots No. 1 and No. 2, is all in slot No. 1. Had there been four slots per pole per phase, this belt would have been distributed in the tops of slots numbers 1, 2, 3 and 4 in the type of Fig. 2, but in the type of Figure 3 would be found concentrated in slots No. 1 and No. 3. There would be a similar change in the distribution of the other belts.

In Fig. 4 the two adjacent coil groups in a given phase are not similar since they contain different numbers of coils, and it takes both of these groups as connected between *A* and *A'* to make a sample unit as far as the electromotive force wave-shape is concerned. It will be observed in this connection that the phase o the electromotive force of the coil 11–16 is half way between that of coil 1-6 and that of coil 3-8. Thus the shape of the electromotive force wave is exactly the same as that of a two-layer winding with the same number (3) of slots per pole per phase. This relation obviously holds for the one-layer winding whenever the number of slots per pole per phase is odd.

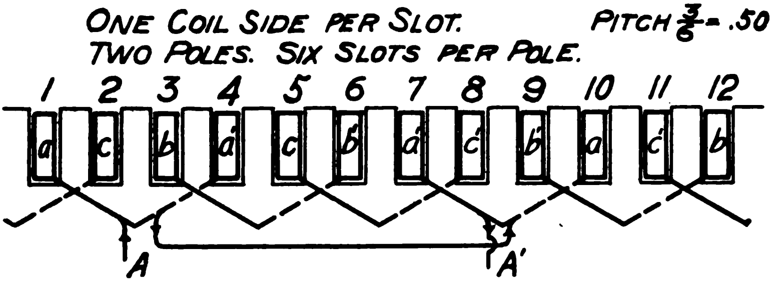

FIG. 3

DIFFERENTIAL FACTOR

In the vector additions of the fundamentals or of the *m*th harmonics of several slot electromotive forces, the vector sum will in general be less than the numerical sum, and the ratio of the former to the latter will be called the *differential-factor*. This name is employed since the real cause of the reduction from numerical to vector sum, is the distribution of

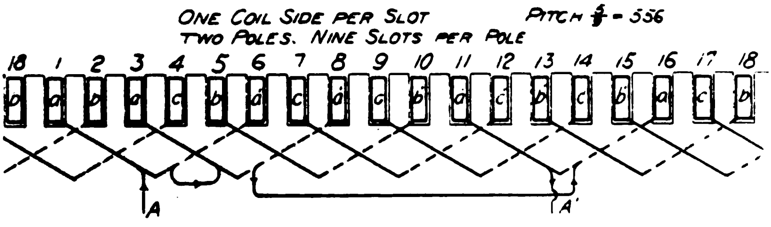

FIG. 4

the winding and the resulting *differential* cutting of flux by the conductors in the several slots of a given phase belt; that is, there are times when some of these slots are cutting positive flux while others in the same belt are cutting negative flux. This differential action is not considerable when the phase belt is narrow as compared with the half wave of flux distribution. For example, in an ordinary three-phase alternator with a belt

60 degrees wide the differential factor for the fundamental flux wave is about 0.96, depending somewhat upon the number of slots per pole; but when this 60-degree belt is considered as cutting the third harmonic flux distribution, the half wave of which spans only 60 degrees, it is obvious that the differential action is much greater. As the belt becomes relatively broader with respect to the length of the harmonic flux wave, the differential action increases and the differential factor decreases until the belt span equals the pitch of the harmonic flux wave. Beyond this point the differential factor becomes negative, again passes through zero and so on as the belt span passes through multiple values of the length of the harmonic flux wave, (see Fig. 7). For example the 120-degree belt of a three-phase converter, or the two adjacent 60-degree belts connected in series between the terminals of a star-connected alternator, would span 360 degrees of the third harmonic flux wave, 3×360 degrees of the ninth, 5×360 degrees of the fifteenth, and so on, the differential factor being zero in each case. That is, these harmonics disappear. Thus although the differential action reduces the fundamental electromotive force, it reduces most of the harmonics to a much greater extent, and tends to make the belt electromotive force more nearly sinusoidal than the slot electromotive force or flux distribution curve.

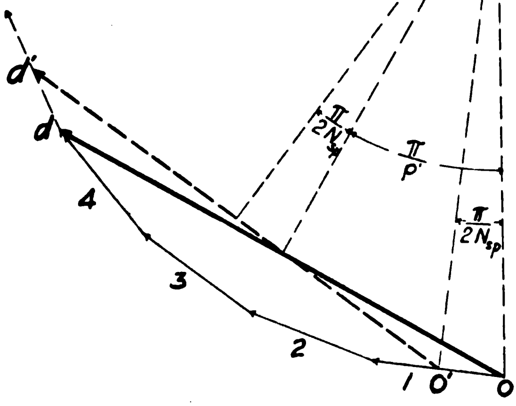

FIG. 5

The effect of a fractional pitch winding is to introduce still further differential action between the two belts which go to make up one coil group, the amount of which depends upon the coil pitch and the harmonic in question.

Belt Differential Factor. Consider first the differential action within a single belt for the case of a two-layer winding. Figs. 5 and 6 show the vector relations of the fundamentals, and the third and the fifth harmonics for a three-phase machine with 12 slots per pole.

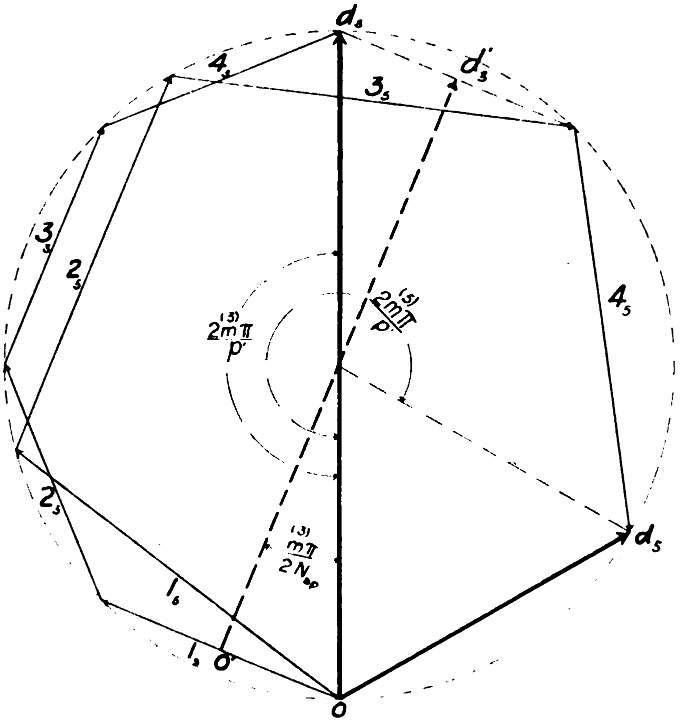

FIG. 6

In Fig. 5, the vectors 1, 2, 3 and 4 represent the four fundamental slot electromotive forces of one phase belt and $\overline{o\,d}$ their resultant. In Fig. 6 the vectors 1_3, 2_3, 3_3 and 4_3 represent the four third harmonic slot electromotive forces of one phase belt and $o\,d_3$ their resultant. Similarly 1_5, 2_5, 3_5 and 4_5 represent the corresponding fifth harmonic slot electromotive forces and $o\,d_5$ their resultant.

Let N_{sp} = slots per pole, and

p' = the number of belt spans per pair of poles, ($p' = 6$ for ordinary three phase).

Then $\frac{\pi}{N_{sp}}$ = the phase difference between the fundamental electromotive forces of two adjacent slots, $\frac{m\pi}{N_{sp}}$ = the phase difference (in mth harmonic radians) between the mth harmonic electromotive forces of two adjacent slots, $\frac{2N_{sp}}{p'}$ = slots per belt, and $\frac{2m\pi}{p'}$ = the total belt span in mth harmonic radians.

TABLE I

BELT DIFFERENTIAL FACTOR

N_{sp}	One coil side per slot	6	12	18	24	30	36	42	48
	Two coil sides per slot	3	6	9	12	15	18	21	24
	$m = 1$	1.00	+0.966	+0.960	+0.958	+0.957	+0.956	+0.956	+0.956
	$m = 3$	1.00	+0.707	+0.667	+0.653	+0.647	+0.644	+0.642	+0.641
	$m = 5$	1.00	+0.259	+0.218	+0.205	+0.200	+0.197	+0.196	+0.194
	$m = 7$	1.00	-0.259	-0.177	-0.157	-0.149	-0.145	-0.143	-0.141
	$m = 9$	1.00	-0.707	-0.333	-0.270	-0.248	-0.236	-0.229	-0.225
	$m = 11$	1.00	-0.966	-0.177	-0.128	-0.109	-0.102	-0.097	-0.095
	$m = 13$	1.00	-0.966	+0.218	+0.128	+0.102	+0.091	+0.086	+0.083
	$m = 15$	1.00	-0.707	+0.667	+0.270	+0.200	+0.173	+0.159	+0.149
	$m = 17$	1.00	-0.259	+0.960	+0.157	+0.102	+0.084	+0.075	+0.070
	$m = 19$	1.00	+0.259	+0.960	-0.205	-0.109	-0.084	-0.072	-0.066
	$m = 21$	1.00	+0.707	+0.667	-0.653	-0.248	-0.173	-0.147	-0.127
	$m = 23$	1.00	+0.966	+0.218	-0.958	-0.149	-0.091	-0.072	-0.063
	$m = 25$	1.00	+0.966	-0.177	-0.958	+0.200	+0.102	+0.075	+0.063
	$m = 27$	1.00	+0.707	-0.333	-0.653	+0.647	+0.236	+0.159	+0.127

If the diagram (Fig. 6) be reduced to unit radius, the resultant of the $\frac{2N_{sp}}{p'}$ mth harmonics will be $2 \sin \frac{m\pi}{p'}$. On the same asis the mth harmonic of the slot electromotive force is

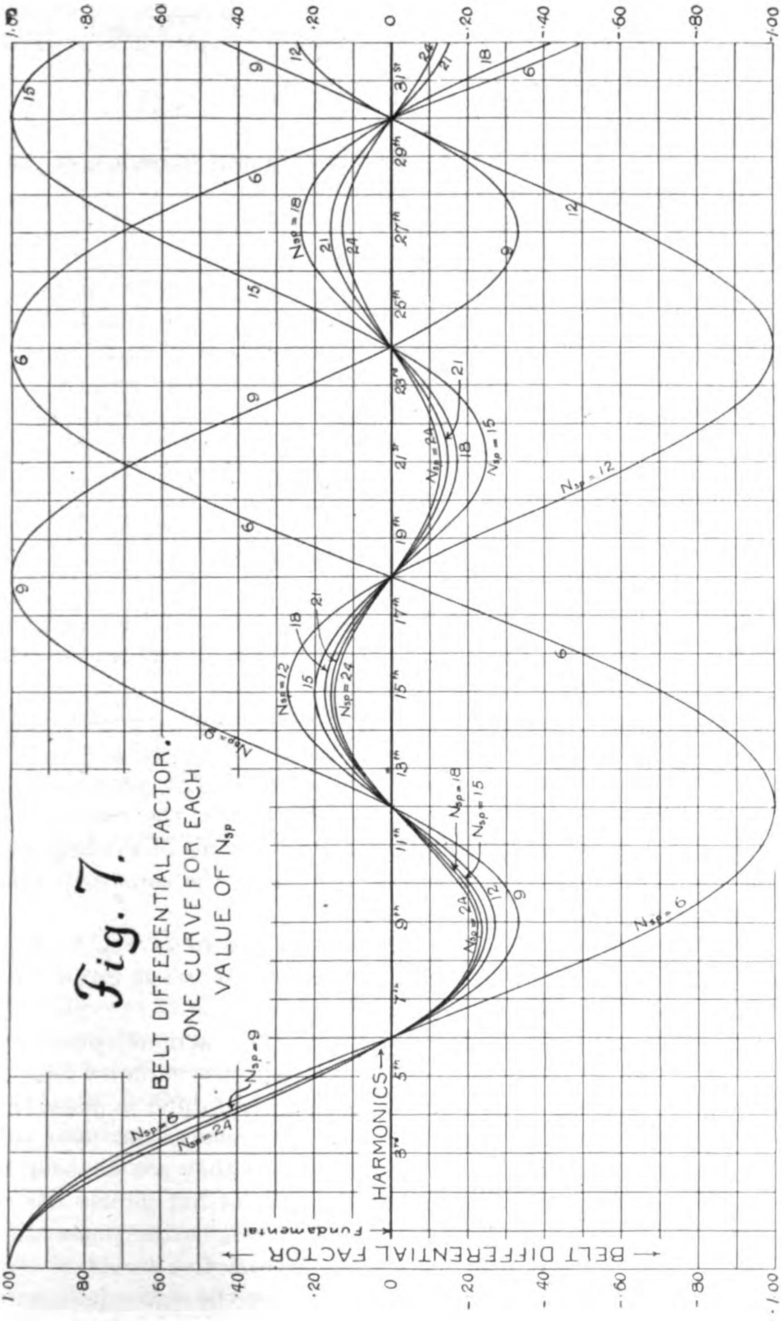

Fig. 7.
BELT DIFFERENTIAL FACTOR.
ONE CURVE FOR EACH
VALUE OF N_{sp}

$2 \sin \frac{m\pi}{2 N_{sp}}$, and the arithmetical sum of the $\frac{2 N_{sp}}{p'}$ mth harmonics is $\frac{2 N_{sp}}{p'} \times 2 \sin \frac{m\pi}{2 N_{sp}}$.

Thus the belt differential factor for the mth harmonic of the belt electromotive force is:

$$k_{dm} = \frac{p'}{2 N_{sp}} \; \frac{\sin \frac{m\pi}{p'}}{\sin \frac{m\pi}{2 N_{sp}}}$$

and that for the fundamental

$$k_{d_1} = \frac{p'}{2 N_{sp}} \; \frac{\sin \frac{\pi}{p'}}{\sin \frac{\pi}{2 N_{sp}}}$$

Values of k_{dm} for a three-phase two-layer winding, for various values of N_{sp} and of m, are given in Table I, and are shown graphically in the curves of Fig. 7.

In the case of a one-layer winding (one coil-side per slot) and an even number of slots per pole, the belt differential-factor will obviously be the same as for a two-layer winding with half as many slots per pole, (see Fig. 3). But when the number of slots per pole is odd, (see Fig. 4), the two types of winding are exactly equivalent in this respect and have the same belt differential-factor.

The belt reduction-factor which is the ratio of k_{dm} to k_{d_1}, differs so little from k_{dm} in most cases that it is not given. It can be readily computed from the table.

Fractional pitch differential-factor. If a fractional pitch or chorded winding be employed, the two belt electromotive forces, though of the same shape and magnitude, will differ in phase by an amount depending upon the pitch deficiency, and their resultant will not have the same shape unless they are sinusoidal.

Let λ_c designate the coil pitch in terms of full pitch. Then $1 - \lambda_c$ is the pitch deficiency, and $(1 - \lambda_c)\, \pi_m$ is the phase difference between the mth harmonic electromotive forces of the two belts, in Fig. 8, where $\overline{OA}$ and $\overline{AB}$ are the two equal mth harmonic electromotive forces and $\overline{OB}$ their resultant. The pitch differential-factor for the *m*th harmonic electromotive force is then:

$$k_{pdm} = \overline{OB} \div 2\,\overline{OA} = \cos \frac{m\,\pi}{2}\,(1-\lambda_c)$$

and that for the fundamental is,

$$k_{pd_1} = \cos \frac{\pi}{2}\,(1-\lambda_c)$$

Values of k_{pdm} for all values of the pitch above 50% are plotted in Fig. 9. *The pitch reduction factor* k_{pm}, which is the ratio of k_{pdm} to k_{pd_1} shows the degree in which the distortion or per cent harmonic is reduced by chording. It is shown in the broken curve of Fig. 9 for the eleventh harmonic only.

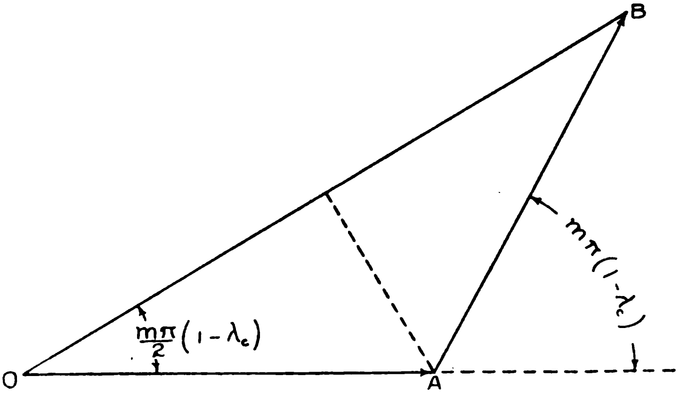

FIG. 8

It will be seen from Fig. 9 that any considerable change of pitch will usually reverse some of the harmonics, and that it is possible practically to eliminate any desired harmonic, or greatly to reduce several of the more important ones, by a proper choice of pitch. For example, a pitch of 0.833 (five slots in 6, 10 in 12, 15 in 18 or 20 in 24) would reduce the fifth, seventh, seventeenth and nineteenth to about one quarter of their full pitch values; then by connecting the phases in star, (which is equivalent to a pitch of 0.667), the third, ninth, fifteenth, twenty-first, etc., may be entirely eliminated. This would leave only the eleventh and thirteenth, which would ordinarily be reduced by the belt differential action to less than 10 per cent of their value in the flux distribution curve, see Table I and Fig. 7.

Mid-coil differential factor. If the phase winding begin and end in the center of a coil rather than at the junction of two coils, there will be two half-coil vectors, as shown in Fig. 5, where $\overline{o' d'}$ is

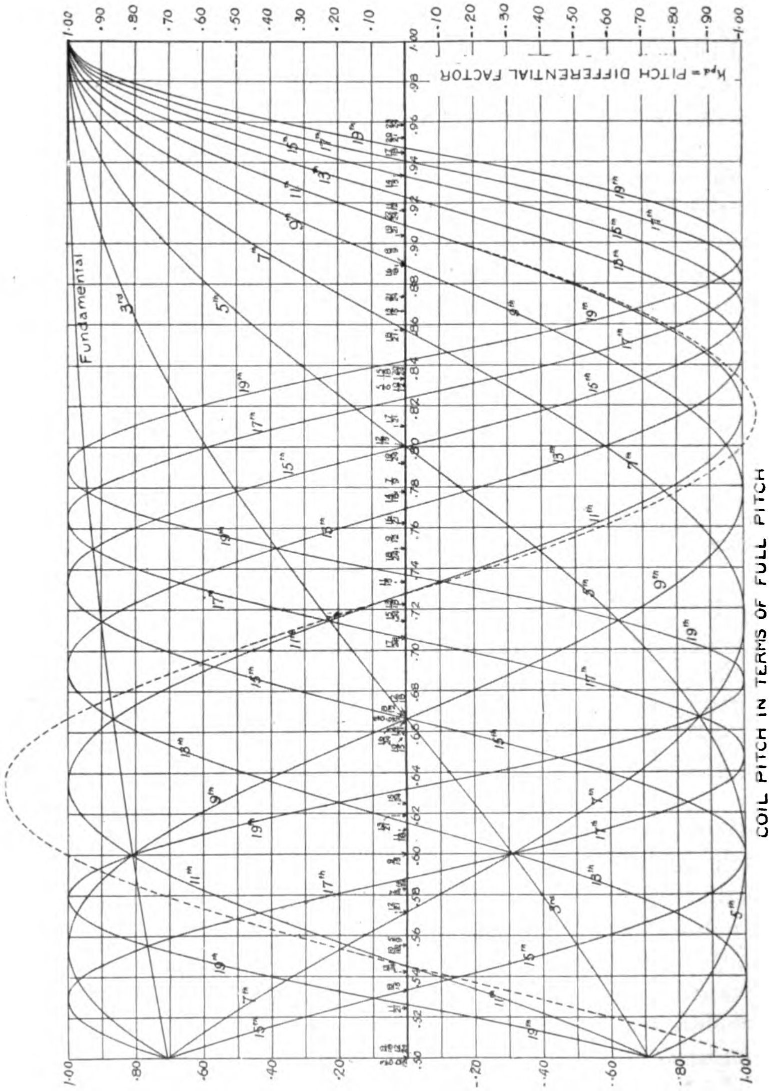

FIG. 9

drawn from the middle of No. 1 electromotive force to the middle of No. 5 electromotive force, and in Fig. 6 where $\overline{o_3' d_3'}$ is drawn from the middle of 1_3 to that of 5_3. The resultant is thus reduced in the ratio.

$$k_{dcm} = \cos\frac{m\pi}{2N_{sp}}$$

which is the *mid-coil differential factor* for the *m*th harmonic.

For the fundamental this is

$$k_{dc_1} = \cos\frac{\pi}{2N_{sp}}$$

and the *mid-coil reduction factor* for the *m*th harmonic is

$$k_{cm} = \frac{k_{dcm}}{k_{dc_1}} = \cos\frac{m\pi}{2N_{sp}} \div \cos\frac{\pi}{2N_{sp}}$$

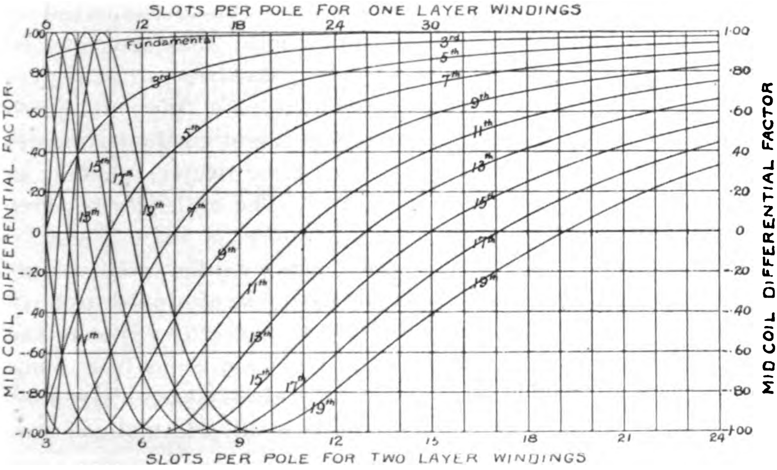

FIG. 10

Since k_{cm} is so nearly equal to k_{dcm}, the latter only is given in the curves of Fig. 10. The values given in Fig. 10 apply strictly only to the two-layer winding, but it has already been shown that in the case of an even number of slots per pole, the one-layer winding is equivalent to a two-layer winding with half as many slots per pole, and that in the case of an odd number of slots per pole, the one-layer winding is wholly equivalent to the two-layer winding.

With ordinary values of N_{sp} some of the higher harmonics are practically eliminated, and others are considerably reduced by the mid-coil connection.

SUMMARY

There are thus several differential actions combining to reduce the electromotive force induced in the armature of an alternator, but they affect the fundamental and the various harmonics in different degrees, the amount of reduction of the fundamental being in general very small as compared with that of the harmonics. These differential actions may be classified as follows:

Belt differential action, between the several slots of each phase belt;

Pitch differential action, between the two belts of each coil group;

Mid-coil differential action, due to the mid-coil connection and the consequent equivalent widening of each belt;

Phase differential action, between two phases connected in series, as with three-phase star connection. This last may be looked upon either as a widening of the phase belt to 120 degrees in place of 60 degrees, or as equivalent to a fractional pitch of two-thirds; it reduces the fundamental and all the harmonics except the multiples of three in the same degree, (0.866), so that their reduction factors are unity. The multiples of three are reduced to zero, see Fig. 9.

By a proper combination of these various differential actions it is possible to reduce all the harmonics of an alternator electromotive force to very low values without seriously reducing the fundamental, even when the flux distribution is far from sinusoidal. For example, a star-connected three-phase alternator, with 12 slots per pole, a coil pitch of 10 in 12, and mid-coil connections, will have per cent harmonics in its electromotive force wave which bear to the per cent harmonics of the flux distribution curve the following ratios, labelled k_r, the *total reduction factor.*

m =	3	5	7	9	11	13	15	17	19	21
k_r =	0.0	0.045	0.023	0.	0.017	0.017	0.0	0.027	0.045	0.0

In this case the least reduction is to less than 5 per cent of the per cent value in the flux distribution curve, and if the largest harmonics in the flux distribution curve were not more than 10 per cent, the largest harmonics in the electromotive force wave would be less than one half of one per cent. But by a proper

TABLE II
TOTAL REDUCTION FACTOR FULL-COIL CONNECTION

		3rd	5th	7th	9th	11th	13th	15th	17th	19th
$N_{sp} = 6$	$\lambda_c = \frac{6}{6}$	+0.732	+0.268	-0.268	-0.732	-1.000	-1.000	-0.732	-0.268	+0.268
	$\lambda_c = \frac{5}{6}$	+0.536	+0.072	+0.072	+0.536	+1.000	+1.000	+0.536	+0.072	+0.072
	$\lambda_c = \frac{4}{6}$	0.000	-0.268	+0.268	0.000	-1.000	-1.000	0.000	+0.268	-0.268
$N_{sp} = 9$	$\lambda_c = \frac{9}{9}$	+0.695	+0.227	-0.185	-0.347	-0.185	+0.227	+0.695	+1.000	+1.000
	$\lambda_c = \frac{8}{9}$	+0.611	+0.148	-0.064	0.000	+0.064	-0.148	-0.611	-1.000	-1.000
	$\lambda_c = \frac{7}{9}$	+0.370	-0.042	+0.151	+0.415	+0.151	-0.042	+0.370	+1.000	+1.000
	$\lambda_c = \frac{6}{9}$	0.000	-0.227	+0.185	0.000	-0.185	+0.227	0.000	-1.000	-1.000
$N_{sp} = 12$	$\lambda_c = \frac{12}{12}$	+0.682	+0.214	-0.165	-0.283	-0.132	+0.132	+0.283	+0.165	-0.214
	$\lambda_c = \frac{11}{12}$	+0.636	+0.172	-0.101	-0.109	-0.017	-0.017	-0.109	-0.101	+0.172
	$\lambda_c = \frac{10}{12}$	+0.499	+0.058	+0.044	+0.207	+0.132	-0.132	-0.207	-0.044	-0.058
	$\lambda_c = \frac{9}{12}$	+0.283	-0.089	+0.165	+0.283	+0.055	+0.055	+0.283	+0.165	-0.089
	$\lambda_c = \frac{8}{12}$	0.000	-0.214	+0.165	0.000	-0.132	+0.132	0.000	-0.165	+0.214
$N_{sp} = 15$	$\lambda_c = \frac{15}{15}$	+0.677	+0.209	-0.156	-0.258	-0.114	+0.107	+0.209	+0.107	-0.114
	$\lambda_c = \frac{14}{15}$	+0.647	+0.182	-0.117	-0.153	-0.047	+0.022	0.000	-0.022	+0.047
	$\lambda_c = \frac{13}{15}$	+0.560	+0.107	-0.017	+0.082	+0.078	-0.998	-0.214	-0.998	+0.078
	$\lambda_c = \frac{12}{15}$	+0.418	0.000	+0.097	+0.258	+0.114	-0.066	0.000	+0.066	-0.114
	$\lambda_c = \frac{11}{15}$	+0.229	-0.114	+0.167	+0.229	+0.013	+0.078	+0.229	+0.078	+0.013
	$\lambda_c = \frac{10}{15}$	0.000	-0.209	+0.156	0.000	-0.114	+0.107	0.000	-0.107	+0.114
$N_{sp} = 18$	$\lambda_c = \frac{18}{18}$	+0.674	+0.206	-0.152	-0.247	-0.106	+0.096	+0.181	+0.088	-0.088
	$\lambda_c = \frac{17}{18}$	+0.653	+0.188	-0.125	-0.175	-0.061	+0.041	+0.047	+0.008	+0.008
	$\lambda_c = \frac{16}{18}$	+0.592	+0.135	-0.053	+0.000	+0.037	-0.063	-0.159	-0.088	+0.088
	$\lambda_c = \frac{15}{18}$	+0.493	+0.055	+0.041	+0.181	+0.106	-0.096	-0.132	-0.240	-0.240
	$\lambda_c = \frac{14}{18}$	+0.358	-0.038	+0.124	+0.294	+0.087	-0.018	+0.096	+0.088	-0.088
	$\lambda_c = \frac{13}{18}$	+0.192	-0.131	+0.167	+0.192	-0.010	+0.087	+0.052	+0.041	+0.041
	$\lambda_c = \frac{12}{18}$	0.000	-0.206	+0.152	0.000	-0.106	+0.096	0.000	-0.088	+0.088

TABLE III
TOTAL REDUCTION FACTOR MID-COIL CONNECTION

		3rd	5th	7th	9th	11th	13th	15th	17th	19th
$N_{sp} = 6$	$\lambda_c = \frac{6}{6}$	+0.536	+0.071	+0.071	+0.536	+1.000	+1.000	+0.536	+0.071	+0.071
	$\lambda_c = \frac{5}{6}$	+0.392	+0.020	−0.020	−0.392	−1.000	−1.000	−0.392	−0.020	+0.020
	$\lambda_c = \frac{4}{6}$	0.000	−0.071	−0.071	0.000	+1.000	+1.000	0.000	−0.071	−0.071
$N_{sp} = 9$	$\lambda_c = \frac{9}{9}$	+0.611	+0.148	−0.064	0.000	+0.064	−0.148	−0.611	−1.000	−1.000
	$\lambda_c = \frac{8}{9}$	+0.536	+0.096	−0.022	0.000	−0.022	+0.096	+0.536	+1.000	+1.000
	$\lambda_c = \frac{7}{9}$	+0.325	−0.027	+0.052	0.000	−0.052	+0.027	−0.325	−1.000	−1.000
	$\lambda_c = \frac{6}{9}$	0.000	−0.148	+0.064	0.000	+0.064	−0.148	0.000	+1.000	+1.000
$N_{sp} = 12$	$\lambda_c = \frac{12}{12}$	+0.636	+0.172	−0.101	−0.109	−0.017	−0.017	−0.109	−0.101	+0.172
	$\lambda_c = \frac{11}{12}$	+0.592	+0.137	−0.063	−0.042	−0.002	+0.002	+0.042	+0.063	−0.138
	$\lambda_c = \frac{10}{12}$	+0.263	+0.072	+0.101	+0.109	+0.007	+0.007	+0.109	+0.101	+0.072
	$\lambda_c = \frac{9}{12}$	+0.465	−0.046	+0.027	+0.080	+0.017	−0.017	−0.080	−0.027	+0.046
	$\lambda_c = \frac{8}{12}$	0.000	−0.172	+0.101	0.000	−0.017	−0.017	0.000	+0.101	−0.172
$N_{sp} = 15$	$\lambda_c = \frac{15}{15}$	+0.646	+0.182	−0.117	−0.153	−0.047	+0.022	0.000	−0.022	+0.047
	$\lambda_c = \frac{14}{15}$	+0.618	+0.159	−0.087	−0.090	−0.019	+0.005	0.000	+0.005	−0.019
	$\lambda_c = \frac{13}{15}$	+0.535	+0.093	−0.012	+0.048	+0.032	−0.021	0.000	+0.021	−0.032
	$\lambda_c = \frac{12}{15}$	+0.400	0.000	+0.072	+0.153	+0.047	−0.014	0.000	−0.014	+0.047
	$\lambda_c = \frac{11}{15}$	+0.219	−0.099	+0.125	+0.136	+0.005	+0.016	0.000	−0.016	−0.005
	$\lambda_c = \frac{10}{15}$	0.000	−0.181	+0.116	0.000	−0.047	+0.022	0.000	+0.022	−0.047
$N_{sp} = 18$	$\lambda_c = \frac{18}{18}$	+0.653	+0.188	−0.125	−0.175	−0.061	+0.040	+0.047	+0.008	+0.008
	$\lambda_c = \frac{17}{18}$	+0.634	+0.171	−0.102	−0.124	−0.035	+0.017	+0.012	+0.000	−0.000
	$\lambda_c = \frac{16}{18}$	+0.574	+0.122	−0.043	+0.000	+0.021	−0.027	−0.041	−0.008	−0.008
	$\lambda_c = \frac{15}{18}$	+0.478	+0.050	+0.033	+0.128	+0.061	−0.041	−0.034	−0.002	+0.002
	$\lambda_c = \frac{14}{18}$	+0.348	−0.034	+0.101	+0.209	+0.049	−0.007	+0.025	+0.008	+0.008
	$\lambda_c = \frac{13}{18}$	+0.187	−0.118	+0.138	+0.137	−0.006	+0.037	+0.013	+0.004	−0.004
	$\lambda_c = \frac{12}{18}$	0.000	−0.188	+0.124	0.000	−0.061	+0.041	0.000	−0.008	−0.008

choice of pole arc it is easy to reduce the fifth harmonic of the flux distribution curve to 5 per cent and since the nineteenth would never be as large as this, the maximum harmonic in the electromotive force wave would in this case be about two tenths of one per cent of the fundamental.

Tables II and III contain values of the *total reduction factor* k_r for a considerable range of values of N_{sp}, m and λ_c. The tables as they stand apply directly to the two-layer winding only, but it will be remembered that a one-layer winding with an odd number of slots per pole per phase is entirely equivalent to a two-layer winding with the same number of slots, and that a one-layer winding with an even number of slots per pole per phase is equivalent (for the present purpose) to a two-layer winding with half as many slots.

EXAMPLES

The curves of Mr. Bache Wiig's Atlantic City paper provided such an excellent illustration of the value of the method above outlined that they are reproduced in Figs. 11, 12, 13 and 14.

Curve I of Fig. 11 is an assumed flux distribution curve or " field form " of a two-pole, three-phase, 60-cycle, 400-kw. turbo-alternator with 12 slots per pole. The other 16 curves were computed from the " field form " by the ordinary method for the various windings indicated on the curves.

The eight curves of Figs. 12 and 14 giving the phase voltage, and the flux distribution curve of Fig. 11, have been analyzed for the purposes of this paper. The results are given with the corresponding calculated values in Table IV.

In making comparisons it should be remembered that there were many opportunities for errors in the original computing, plotting, reproducing, transcribing, and analyzing. The method of analysis employed is that of Fischer Hinnen* and while it is very simple, it suffers from the fact that the correction made necessary in any lower harmonic by the presence of a multiple of that harmonic, is of the full magnitude of that multiple. This requires for reasonably accurate results that the analysis be carried to the higher multiples; but the probable error in the determination of these higher multiples is so great that it renders the lower harmonics less accurate than would otherwise be possible. The slice or strip† method in which areas are used instead of ordinates, is more accurate in this respect when carefully carried out, but the amount of labor involved for accurate results was too great for the task in hand.

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* " Electrotechnische Zeitschrift", May 9, 1901; also " Electric Journal ", 1908.

† Houston and Kennelly in " Electrical World ", 1898.

After carrying the analysis of all the curves to the nineteenth harmonic, it was surmised that the correction due to still higher harmonics might have a considerable effect. This was found to be true by carrying the analysis of the flux distribution curve

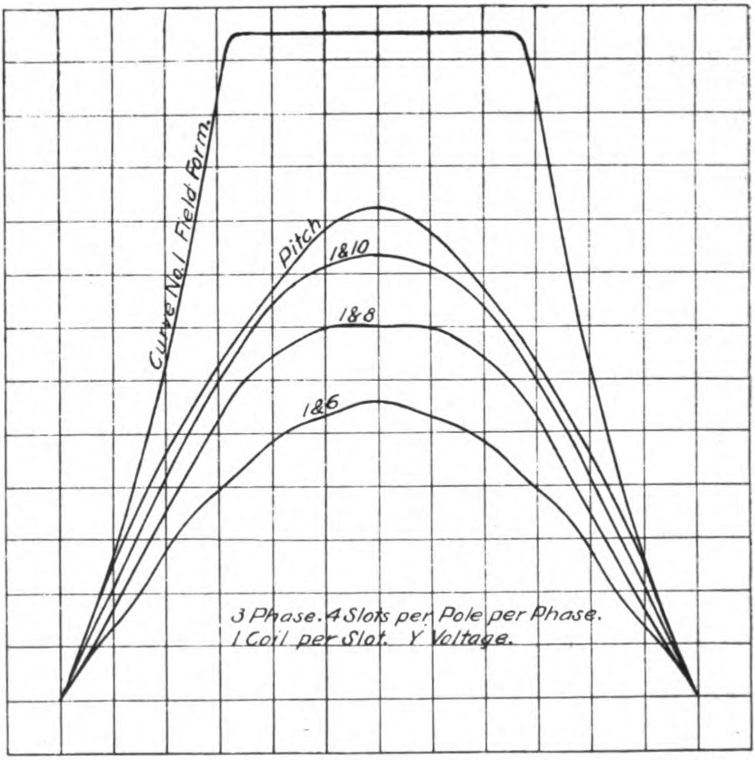


Fig. 11

to the twenty-seventh harmonic, but time was not available for carrying the analysis of the other curves to the same point, so that some of the minor discrepancies are doubtless due to this omission.

Referring now to Table IV:

Under "*flux distribution curve*" are given the results of the analysis of that curve, (Fig. 11), the harmonics being given in per cent of the fundamental.

TABLE IV

ANALYSIS AND CALCULATIONS OF BACHE-WIIG'S CURVES

			Pitch curve $\lambda_c = 1$		" 1 & 10 " curve $\lambda_c = \frac{9}{12} = .75$			" 1 & 8 " curve $\lambda_c = \frac{7}{12} = .583$			" 1 & 6 " curve $\lambda_c = \frac{5}{12} = .417$		
	Harmonics	Flux dist. curve	Analyzed from *B-W* pitch curve	Calc. from flux dist.	Anal. from *B-W* " 1 & 10 " curve	Calc. from pitch curve	Calc. from flux dist.	Anal. from *B-W* " 1 & 8 " curve	Calc. from pitch curve	Calc. from flux dist.	Anal. from *B-W* " 1 & 6 " curve	Calc. from pitch curve	Calc. from flux dist.
One Layer Winding. One Coil-side per slot. Fig. 12	Fundamental	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	3rd Harm.	+2.46	+1.78	+1.80	+0.86	+0.73	+0.74	0.10	-0.86	-0.87	-2.80	-2.70	-2.73
	5th “	-8.80	-1.91	-2.36	+0.94	+0.79	+0.97	+3.66	+2.39	+2.95	+0.43	+0.41	+0.50
	7th “	-1.32	+0.5	+0.35	-0.44	-0.50	-0.35	+1.11	-0.08	-0.06	+0.48	+0.81	+0.57
	9th “	+2.46	-0.6	-1.80	+1.75	+0.60	+1.80	-0.84	-0.70	-2.09	+0.9	+0.38	+1.13
	11th “	+0.09	+0.04	-0.09	+0.04	-0.02	+0.04	+0.78	+0.03	-0.07	0.0	-0.05	+0.12
	13th “	-1.42	+0.06	+1.42	+0.46	+0.02	+0.58	-0.02	-0.04	-1.09	+1.26	+0.08	+1.85
	15th “	-0.03	0.0	+0.02	0.00	0.00	+0.02	+0.02	0.0	-0.02	0.0	0.0	+0.01
	17th “	+0.81	+0.06	-0.22	0.0	+0.06	-0.22	0.0	+0.01	-0.03	-0.11	-0.10	+0.36
	19th “	-0.02	-0.05	0.0	+0.05	-0.02	-0.00	0.0	-0.06	-0.00	0.0	-0.01	0.0
Two layer winding. Two coil-sides per slot. Fig. 14.	Fundamental	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	3 d Harm.	+2.46	+1.44	+1.66	+0.96	+0.59	+0.68	-0.41	-0.69	-0.80	-2.47	-2.18	-2.51
	5th “	-8.80	-1.88	-1.89	+0.29	+0.78	+0.78	+1.88	+2.35	+2.36	—	+0.40	+0.41
	7th “	-1.32	+0.22	+0.22	-0.35	-0.22	-0.22	+0.17	-0.04	-0.04	+0.54	+0.36	+0.36
	9th “	+2.46	-0.36	-0.69	+0.62	+0.36	+0.69	—	-0.42	-0.80	+1.07	+0.23	+0.44
	11th “	+0.09	-0.23	-0.01	-0.35	+0.09	—	—	-0.18	-0.01	—	+0.30	+0.01
	13th “	-1.42	-0.12	-0.20	-0.15	-0.05	-0.08	+0.12	+0.09	+0.15	-0.14	-0.16	-0.26
	15th “	-0.03	-0.12	-0.01	-0.2	-0.12	-0.01	-0.16	+0.14	+0.01	-0.24	-0.08	-0.01
	17th “	+0.81	-0.06	+0.13	-0.2	-0.06	+0.13	—	-0.01	+0.02	—	+0.10	-0.21
	19 “	-0.02	-0.04	0.00	—	-0.02	—	—	-0.05	—	—	-0.01	—

Under "*pitch curve*" are compared the analyzed harmonics of the full pitch curve with those obtained by calculation from the harmonics of the flux distribution curve by means of Table I.

Under "1 *and* 10 *curve*" are compared the analyzed harmonics of the "1 and 10" curve with those obtained by calculation from both the pitch curve and the flux distribution curve.

The same explanation applies to the other fractional pitch curves.

Referring to the two columns under "pitch curve" in Table IV there are only two out of the eighteen comparisons where the computed harmonic differs by more than a reasonable error from that obtained by direct analysis.

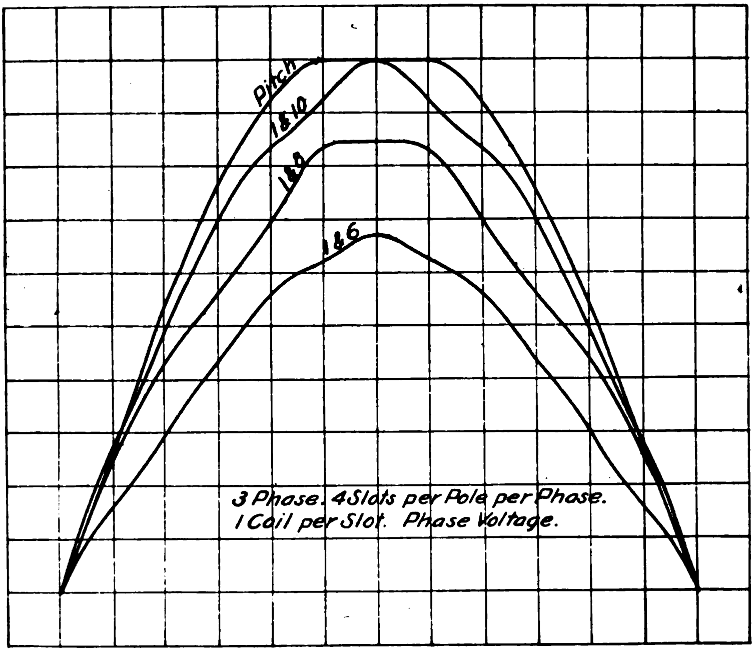


FIG. 12

Referring to the remainder of the table relating to the fractional pitch curves, the results calculated from the flux distribution curve are on the average closer to those obtained by direct analysis than those computed from the pitch curve, showing that some of the above-mentioned discrepancies under "Pitch Curve" were in the pitch curve itself or in its analysis, rather than in the flux distribution curve or in its analysis. This is reasonable since the flux curve harmonics, being larger, are determinable with a smaller percentage error.

The only considerable discrepancies in the fractional pitch results are those for the " 1 and 8 " curve and the one layer winding, and it is altogether likely that there was some slip in the original computation or plotting of this curve, since the results for the same pitch in the two-layer winding, computed from the same flux harmonics, are much closer.

Referring again to Fig. 12 it is interesting to note the reversal of the harmonics in passing from one pitch to another as indicated by the curves of Fig. 9.

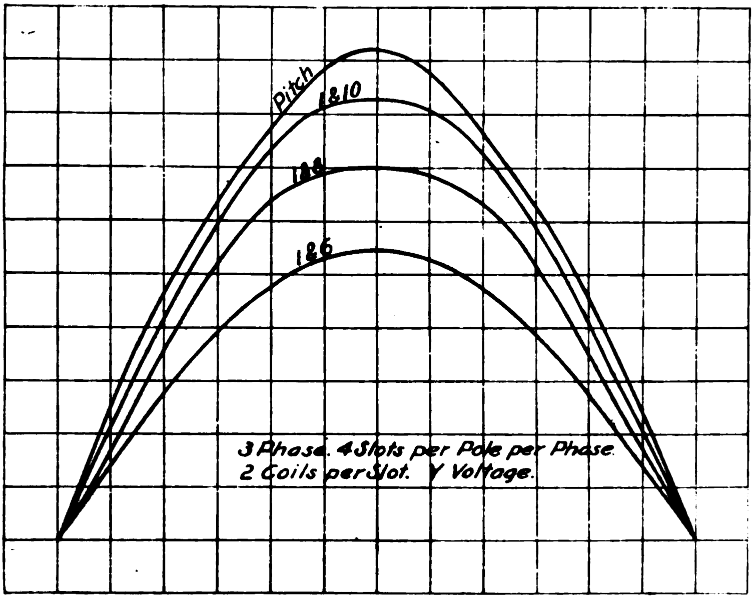


FIG. 13

Thus all the results shown in the curves of Figs. 11, 12, 13, and 14 can be obtained in a much more useful form and with greater accuracy than by the ordinary method and with the expenditure of a small fraction of the time.

As another example, Fig. 15 shows an observed flux distribution curve for a two-pole, 300-kw. turbo-alternator.

Table V gives the harmonic analysis of this curve together with the harmonics of the phase electromotive forces for all possible pitches down to 50 per cent (assuming $N_{sp} = 12$), from which it appears that with star connection to wipe out the third, ninth, and fifteenth harmonics, no one of these windings would give an electromotive force with any single harmonic larger than one per cent of the fundamental. This is not at all an extreme case since the pole arc is normal, being about 65 per cent. of the pole pitch.

By employing the two-layer winding, star connection, and a pitch of ten slots or 83.3 per cent, the harmonics would assume the following values, in per cent of the fundamental, the largest being less than two tenths of one per cent, and the others less than five hundredths.

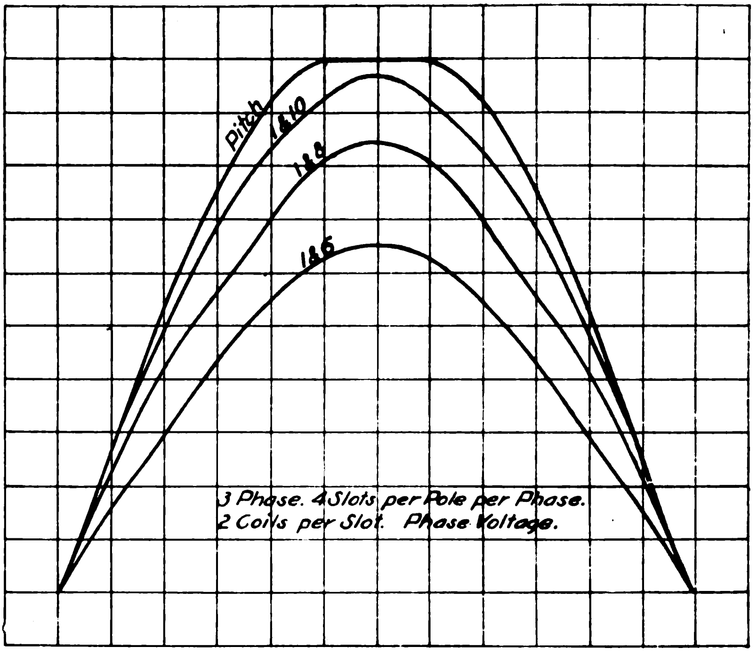


Fig. 14

m =	1	3	5	7	9	11	13	15	17	19
% =	100.0	0.0	0.043	0.003	0.0	0.15	0.0	0.0	0.0	0.002

of one per cent.

Conclusion. It is fully realized that there are several considerations beside that of wave-shape which affect the choice of winding type in an alternator, but there are certainly some

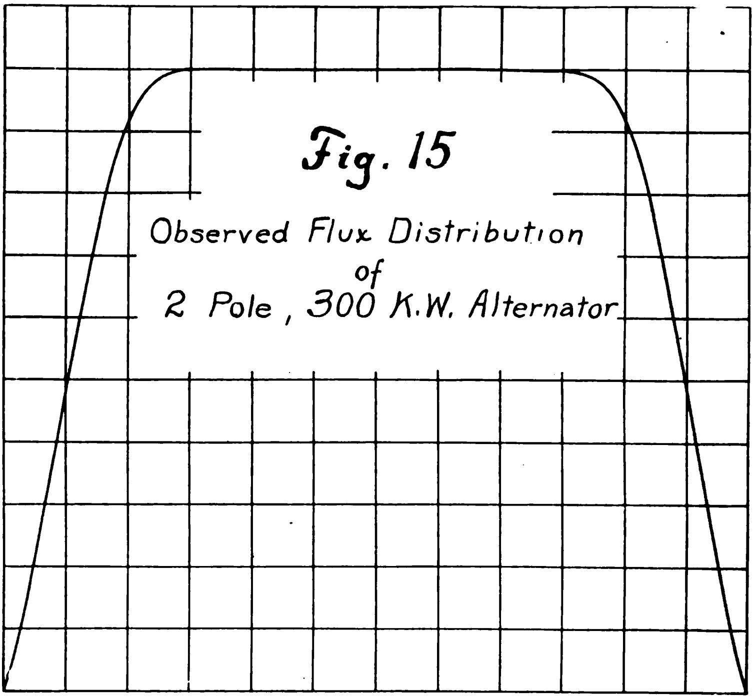
TABLE V

	Harmonics	Flux distribution curve	Pitch curve $\lambda_c = 1$	" 1 & 10 " curve $\lambda_c = \frac{9}{12} = 0.75$	" 1 & 8 " curve $\lambda_c = \frac{7}{12} = 0.583$	" 1 & 6 " curve $\lambda_c = \frac{5}{12} = 0.417$
One-layer winding. One coil side per slot.	Fundamental	100%	100%	100%	100%	100%
	3 d Harm.	20.6	15.1	6.21	-7.27	-22.8
	5th "	2.83	0.76	-0.31	-0.95	-0.16
	7th "	-0.30	0.08	-0.08	-0.013	0.13
	9th "	-1.90	1.39	-1.39	+1.62	0.87
	11th "	-0.80	.80	-0.33	+0.61	1.04
	13th "	0	0	0	0	0
	15th "	0	0	0	0	0
	17th "	0	0	0	0	0
	19th "	-0.12	-0.032	-0.013	-0.04	+0.007

	Harmonics	Flux distribution curve	Pitch curve $\lambda_c = 1$	" 1 & 12 " curve $\lambda_c = .916$	" 1 & 11 " curve $\lambda_c = 0.833$	" 1 & 10 " curve $\lambda_c = 0.75$	" 1 & 9 " curve $\lambda_c = 0.667$	" 1 & 8 " curve $\lambda_c = 0.583$	" 1 & 7 " curve $\lambda_c = 0.50$
Two-layer winding Two coil sides per slot.	Fundamental	100%	100%	100%	100%	100%	100%	100%	100%
	3rd Harm.	20.6	14.05	13.1	10.5	5.79	0	-6.77	-14.05
	5th "	2.83	0.61	0.49	0.16	-0.25	-0.61	-0.76	-0.61
	7th "	-0.30	0.05	0.03	-0.013	-0.05	-0.05	-0.01	+0.05
	9th "	-1.90	0.54	0.21	-0.39	-0.54	0	+0.62	+0.54
	11th "	-0.80	0.152	0.02	-0.15	-0.06	+0.15	+0.12	-0.15
	13th "	0	0	0	0	0	0	0	0
	15th "	0	0	0	0	0	0	0	0
	17th "	0	0	0	0	0	0	0	0
	19th "	-0.12	0.026	-0.022	+0.007	+0.01	-0.026	+0.012	-0.026

instances where an accurate knowledge of the relation of winding type to wave-shape would materially influence the choice of the former much to the advantage of the latter. Also, even when certain harmonics are practically absent from the flux distribution curve at no load, they may be present under full-load distortion, so that the choice of a winding with low reduction factors (see Tables II and III) is in general desirable, other things being equal.

Finally the knowledge as to which harmonics can be practically eliminated by a possible choice of winding makes it possible to choose the pole arc, or shape the pole face, so as to eliminate the principle remaining harmonics. A good example of this is given above, and illustrated in Fig. 15.



The writer wishes to take this opportunity of thanking Mr. Bache-Wiig for the use of the curves of Figures 11, 12, 13, 14 and 15, and Mr. Julian Tynz for his careful analysis of these curves.

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METHOD OF TESTING TRANSFORMER CORE LOSSES, GIVING SINE-WAVE RESULTS ON COMMERCIAL CIRCUITS

BY L. W. CHUBB

It is well known that if the wave-shape or the frequency varies from the normal, the loss in a transformer core at normal voltage varies also. It is obvious, however, that the normal loss, that is, the loss with the sine-wave shape and the normal frequency of, say, 60 cycles, can be obtained under the abnormal conditions of wave shape and frequency by either raising or lowering the voltage. What is needed then, is an indicator which will enable the voltage to be so adjusted that the loss in a transfomer core as measured upon an ordinary wattmeter will be the same as it would be at normal voltage on a circuit having a sine-wave shape of normal frequency.

Suppose such an instrument or indicator was so made that when connected to an alternating-current circuit, it would indicate the effective value of a sine-wave voltage of a certain normal frequency, such as 60 cycles, which would cause the same watt loss in a transformer core as the circuit to which it is connected. For core-loss tests it would be necessary simply to adjust the voltage of the circuit so that the special instrument would indicate the normal voltage, say, 110 volts, although an ordinary voltmeter might read several volts higher or lower, and take a wattmeter reading of the input to the transformer under test. This reading then will be the same as would be found if the measurement were made at 110 volts on a 60-cycle circuit having a sine wave of voltage. Such an instrument, termed as an iron-loss voltmeter, is described in this paper, which takes up in some detail the practical importance of the subject of transformer core-loss tests, the nature and magnitude of errors, and the methods proposed for correcting them.

To the central-station operator, or user of distributing or power transformers, the iron loss of his transformer is of the greatest importance. But of all tests on electrical apparatus one of the most difficult to check and agree upon is the measurement of the core loss of a shunt transformer. Reports of tests for the same transformer taken at different times or in different places will seldom agree within three or four per cent, and often differ as much as ten per cent. The difference is sometimes due to an actual change in the transformer, such as aging of the iron core or a change in the mechanical make-up, or physical stresses of the core due to extreme temperature changes or vibrations during transportation.

Changes in testing conditions and errors of testing methods, however, are more often responsible for the differences and errors in core-loss results. Frequency, temperature and wave-shape variations; wattmeters which are inaccurate on low power-factor tests; voltage control by inductance and resistance; connecting voltmeter and wattmeter pressure leads on the line side of the wattmeter; and paralleling windings which are of wrong ratio, are all frequent sources of error. Of all these the wave-shape difficulties are the most serious, are almost always present, and have been the most difficult for which to make corrections in the usual commercial tests.

The voltage wave-shapes of alternating-current circuits differ greatly. The difference or variation from the sine may be inherent in the alternator, or distortions may be caused by abnormal conditions of load and voltage drops in the circuits. Such voltage distortions are generally caused by having high inductance and resistance in the circuit such as the alternator armature, the coils of measuring instruments, and the rheostats and choke coils which are often used to regulate the voltage. A peaked wave of voltage will cause a lower core loss, and a flat wave a higher loss than a sine wave of the same effective voltage.

On account of this variation with wave-shape, it is desirable that the core-loss tests and data for transformers be expressed in terms of some certain wave-shape, as well as frequency and voltage. Guarantees of core losses are generally based on a sine wave, but we sometimes find them stated in terms of an "average commercial wave." The wave-shapes of commercial circuits may vary between wide limits, and in the majority of cases will be found to be peaked, especially at the terminals of a transformer under test.

The Standardization Rules for a sine wave allow a deviation from the equivalent sine of ten per cent of the maximum ordinate of the equivalent sine wave. If instead of a true sine wave, this nominal sine is to be used as a basis for core-loss guarantees, the conditions of test and results obtained will still be indefinite. Figs. 1 and 2 show two waves which meet sine-wave specifications, but a transformer tested for core loss on them will differ from 7.8 per cent below to 5.8 per cent above the loss which would be obtained on the equivalent sine. These are, of course, theoretical waves, but they show the limit of core-loss error for an average transformer, caused by waves which meet sine-wave specifications.

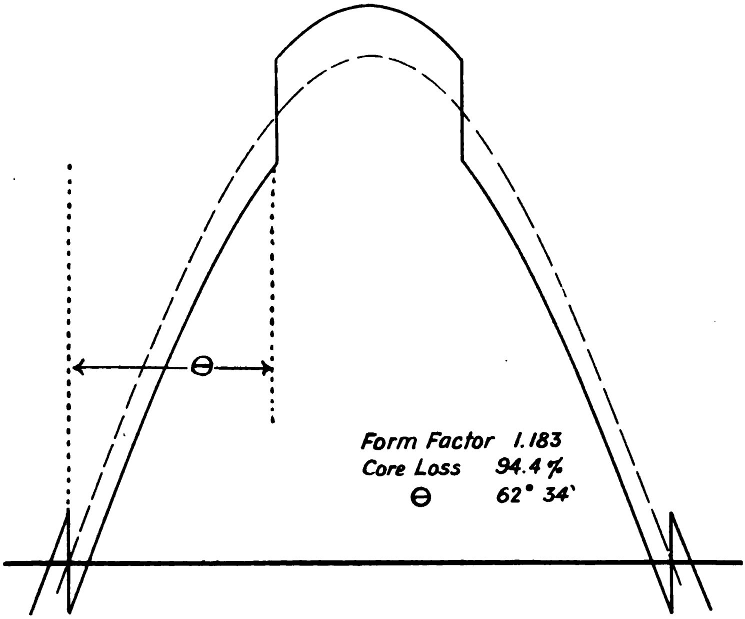


FIG. 1

On account of the accuracy required for core-loss tests, the difficulty of obtaining a good sine wave for test, and the difficulty of correcting results to a sine value by the methods which are now in vogue, it seems very desirable that a method of test be available which will remove the wave-shape difficulty.

It is the purpose of this paper to present a method of testing which will give sine-wave values of transformer core losses on very distorted testing waves, without the aid of an oscillograph, contactor, synchronous commutator, or even exact knowledge of the wave-form or frequency of the circuit.

The iron loss of a transformer consists of the eddy-current loss and the hysteresis loss which are present in about the same relative proportions in transformers designed for the same frequency. The eddy-current loss in a given transformer is dependent upon the root mean square of the instantaneous values of the induced voltage, while the hysteresis loss is dependent upon the maximum magnetic induction in the iron, which in turn is dependent upon the average of the instantaneous values of the induced or counter voltage. This dependence of eddy loss upon root mean square volts and of hysteresis upon average volts, is practically independent of wave-shape variation, except in cases when the voltage curve passes through zero more than twice per cycle;[*] or the flux distribution is varied; or the impedance to high-frequency components of the eddy loss varies greatly.

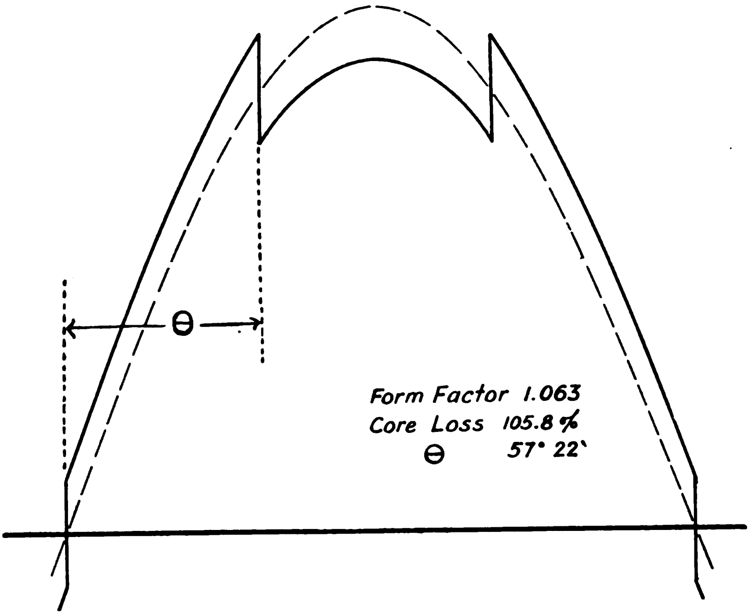


Fig. 2

It is obvious that if the usual alternating-current voltmeter is used to adjust voltage in core-loss tests and the wave-shape of voltage is not a sine, then the eddy loss in the transformer will be correct; that is, the sine value and the hysteresis loss will be low or high, depending upon whether the form-factor of voltage is respectively above or below 1.11. If the average voltage reading, taken from a voltmeter indicating the average, not the root mean square, voltage, or a synchronous rectifying commutator is used for the adjustment of voltage, the hysteresis loss will be correct and the eddy loss will be high or low to agree with the high or low form-factor of voltage.

The total loss as measured in either of the foregoing methods is therefore not a sine-wave result unless the wave of impressed voltage has a form-factor of 1.11. To obtain a sine-wave result of total loss on a distorted wave, either of the following is necessary:

Determine the form-factor and make the proper corrections.

Adjust the testing voltage by an instrument whose readings are such a function of both the average and effective voltage that when it reads the normal voltage of the transformer, the error in the eddy loss will be equal and opposite to the error in the hysteresis loss, thus giving a correct total or core loss.

Suppose a 110-volt, 60-cycle transformer is to be tested and that the result of the core loss is required in terms of a sine wave of impressed voltage. The testing circuit available has a wave-form of unknown shape, and there are no convenient means of finding the form-factor of the wave. Suppose another very small transformer to be on hand with the same ratio of eddy loss to hysteresis loss at 110 volts, 60 cycles, as the first transformer, the sine-wave core-loss of the second transformer being 20 watts at 110 volts, 60 cycles. This small transformer and a wattmeter may be used in determining the proper voltage at which to test the unknown core loss in the larger transformer, on the given circuit. The voltage of the circuit should be adjusted until the energy input to the small transformer core is 20 watts, as indicated by the wattmeter. The core loss in the larger transformer is then read on a separate wattmeter, and the value thus obtained will be the same as would be measured at 110 volts on a 60-cycle sine wave of voltage. The above contains the essential elements of a method which will give sine-wave results of shunt-transformer core losses on any commercial alternating-current circuit.

The scheme is practically carried out by the use of a portable direct-reading instrument, known as an iron-loss voltmeter. This instrument indicates the effective or root mean square value of a sine wave of voltage which would cause the same iron loss in a transformer as the wave of voltage to which the instrument is connected will cause in the same transformer.

The iron-loss voltmeter consists essentially of a ring or core of laminated steel excited by a winding, and a wattmeter of suitable design on which to read the power input to the ring and all copper circuits in the instrument. The core and meter are mounted in suitable wooden cases, the instrument appearing as in Fig. 3. All connections are made inside of the instrument so that there are but two terminal posts to which the line is connected, as is the case in standard alternating-current voltmeters. Fig. 4 shows the arrangement of the circuits in the meter.

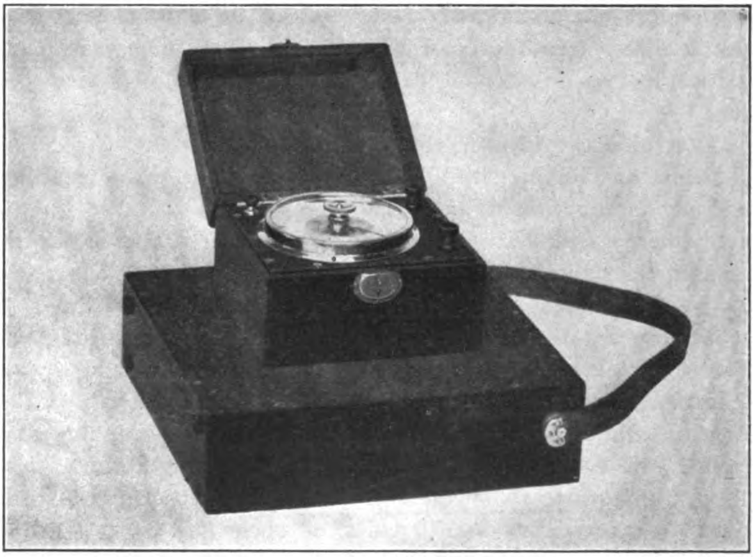


Fig. 3

On the laminated core *C* is placed a winding *W*, the core member and winding being securely mounted in the lower case, and the two leads of the winding brought through the top and into the instrument case, which contains the meter movement.

A stationary current coil *S* is connected in series with the winding *W* and the terminals *P P*. The shunt circuit consists of the moving coil *M*, the non-inductive resistance *R*, and the compensating or adding coil *C C*, which is wound parallel to the series coil and of an equal number of turns. It can be readily seen that the deflection of the wattmeter movement will be caused by the total input to the instrument. This input is the hysteresis and eddy loss in the ring or magnetic rheostat, and the $I^2 R$ losses in all copper circuits of the instrument.

Of these losses the hysteresis in the magnetic rheostat is dependent upon the average value of the terminal voltage, and the eddy-current loss in the rheostat and the copper losses in the shunt circuit are dependent upon the effective value of the terminal voltage. The loss in the series circuit is a complex function of both the average and effective voltage, being proportional to the square of the exciting current of the ring. This series copper loss is so small that the exact law of its dependence on wave-shape is of no importance. The relative proportion of these component losses in the instrument is of importance.

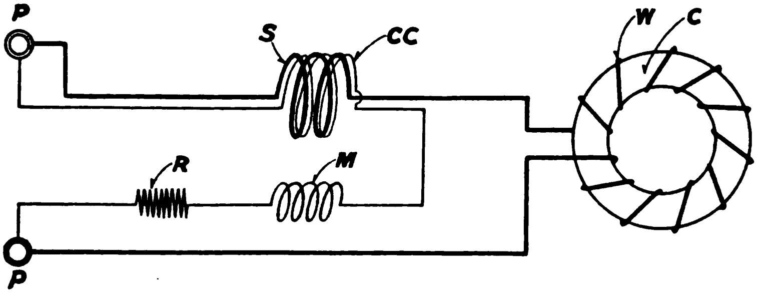


FIG. 4.—Internal connections of iron loss Voltmeter

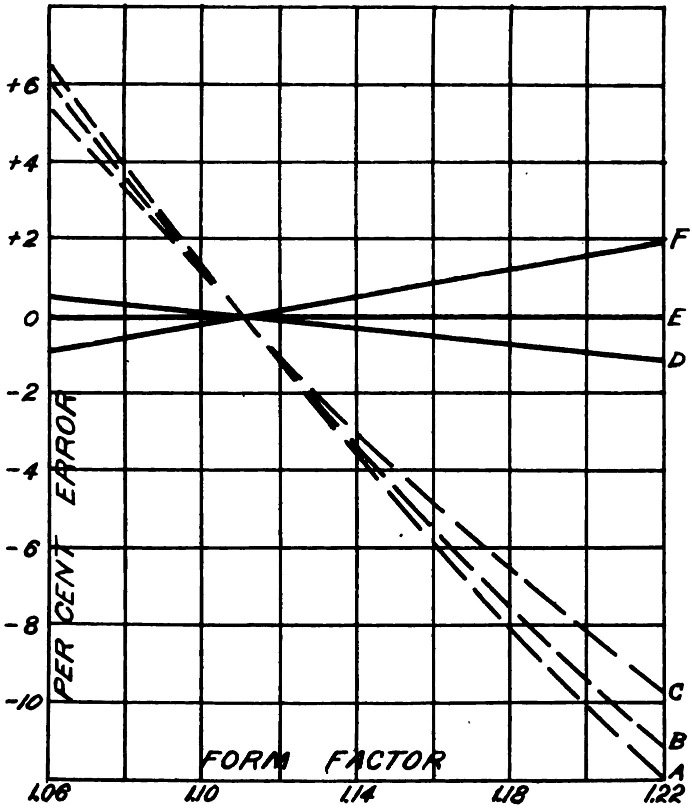
Before calibrating the instrument for a certain frequency, the adjustment of the ratio of eddy loss in the ring plus shunt copper loss, to the total loss, is made by changing the non-inductive resistance in the shunt circuit and the turns on the ring. This ratio of $I^2 R$ losses to total loss is made to be 20 per cent at about six-tenths of full scale voltage. After this adjustment is made, the instrument is calibrated in parallel with an alternating-current voltmeter on the pure sine-voltage wave of the required frequency from a small smooth-core alternator. The scale is drawn in to agree with the alternating-current instrument.

The iron-loss voltmeter, constructed and calibrated as described, may be used as a portable voltmeter in testing transformer core losses on any reasonably distorted wave of voltage. The test may be conducted without any knowledge of the waveform. The voltage may be regulated through a considerable range by the aid of resistance or inductance, thus dispensing with the usual multi-voltage transformer or means of varying the field current of the alternator. The frequency need only approximate the normal value; and the final result of core loss as measured on a wattmeter will be the value which would be obtained on a sine wave of voltage at the normal frequency and voltage of the transformer.

By the Steinmetz formula the hysteresis loss in iron at constant frequency varies practically as the 1.6 power of the induction. This approximate exponent of 1.6 differs somewhat for different samples of sheet steel and it varies with changes of magnetic induction in the same sample of steel. If the hysteresis exponents of the iron in the voltmeter and the iron of the transformer are not equal, an error is introduced theoretically, but in no case of a commercial transformer or a commercial test is this difference of exponent great enough to introduce appreciable errors.

Another condition of a theoretically correct result is that the per cent of $I^2 R$ loss in the voltmeter and transformer shall agree at the testing voltage. Rather wide variations in this relation will, however, introduce errors which are very small in comparison to those obtained by using a root mean square voltmeter. No error is present on a sine wave, no matter what the relation of eddy and hysteresis may be in the transformer and instrument. When the wave-form is distorted the usual method of testing will introduce large errors and the iron-loss voltmeter method will be correct or introduce comparatively small errors. The curves of Fig. 5 show the per cent error that would be obtained when testing transformers of varying per cent eddy loss by the use of the root-mean-square voltmeter and an iron-loss voltmeter having 20 per cent eddy loss at the point of test.

Curves *A*, *B* and *C* show the errors which would be obtained by using the root-mean-square voltmeter in testing three transformers with 14 per cent, 20 per cent and 30 per cent eddy loss respectively on wave-shapes which have form factors ranging from 1.06 to 1.22. Curves *D*, *E* and *F* show the corresponding errors which would be obtained on the three transformers when using the iron-loss voltmeter. Notice that the transformer with 20 per cent eddy loss can be tested without error on any wave-form by the new method, because the instrument assumed has 20 per cent copper loss. Sixty-cycle transformers of commercial design will be found to have about 14 per cent to 30 per cent eddy-current loss and to average about 20 per cent eddy

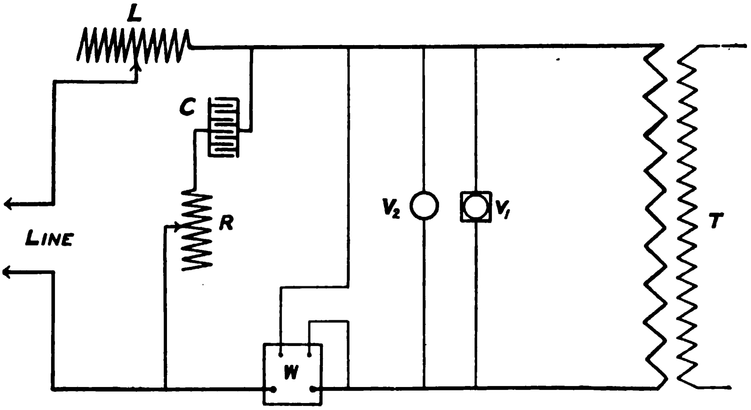


Curve	Transformer with	Tested with
A	14% eddy loss	R.m.s. voltmeter
B	20% " "	R.m.s. "
C	30% " "	R.m.s. "
D	14% " "	Iron "
E	20% " "	Iron "
F	30% " "	Iron "

FIG. 5.—Curves showing effect of ratio of eddy and hysteresis loss on core loss tests by the two methods

loss at normal voltage. Curve *B* then shows the usual errors by the old method. The errors by the new method will seldom be more than one per cent and, even with the worst proportions of eddy and hysteresis loss and worst wave-shapes, will not exceed two per cent.

The foregoing method gives all that should ever be required for commercial accuracy, but as a point of interest a method of form-factor correction is presented which will eliminate even the small errors caused by unequal ratios of component losses already discussed. This method will give a theoretically correct result of core loss for laboratory tests or when great accuracy is required. The form-factor of the voltage wave is first corrected to 1.11 and the loss is then read.



T—Transformer under test, *W*—Wattmeter, V_1—Iron-loss voltmeter, *V* —Root mean square voltmeter, *R*—Variable resistance, *L*—Variable inductance, *C*—Aluminum electrolytic cell

FIG. 6.—Connections for correcting voltage form-factor

As shown in Fig. 6, an inductance *L* is placed in series with the line and an aluminum electrolytic cell *C* is connected across the line and between the inductance *L* and the wattmeter *W*. The inductance causes a peak in the wave, and the aluminum cell, which is working above its critical voltage, short-circuits or flattens out the peaks until the form-factor is 1.11. This correction or adjustment of form-factor is made by varying the resistance *R* and the inductance *L*. When the readings of the root-mean-square voltmeter and the iron-loss voltmeter agree, the form-factor is 1.11 and the core-loss reading is taken. This method does not necessarily give a sine wave for the test but it gives a wave having the same form-factor, and has been found to be very accurate.

Some specimen tests are shown herewith for the sake of clearness and to give an idea of the accuracy and commercial value of the method. Table I shows comparative tests on two 3000-kw., 60-cycle transformers by the usual method and by the iron-loss voltmeter method. Voltage was taken from a 115-volt tap in the low-tension winding. It will be noted that such large units distorted the wave-form enough to make serious errors. Each transformer was tested alone by each method and the sum of the separate tests compared with a test made with both in parallel. Assuming the separate tests by the new method and their sum to be correct, it will be noted that the test with both in parallel by the new method checks within 1.1 per cent, which is within the error of observation. Also note that by the root-mean-square voltmeter method, *A* alone gives a result 6.2 per cent low; *B* alone, 4.5 per cent low, and the parallel test does not agree with the sum of the separate tests and is over 11 per cent below the correct sine value.

TABLE I.

Test No.	Transformers tested	Core loss in kilowatts	
		Iron loss voltmeter method	root-mean-square voltmeter method
1	*A*, alone	17.7	16.6
2	*B*, alone	17.8	17.0
	Sum of separate tests	35.5	33.6
3	Both tested in parallel	35.1	31.5

Table 2 shows a similar comparative test on three smaller transformers, made with an alternator having a good sine wave at no load. The results of the last column show the errors of the root-mean-square voltmeter method under conditions which were supposed to be very good. They also show how consistent the results of the new method are. Tests numbered 5 and 10 were made with some inductance in series with the line. It will be seen by the voltmeter readings of test 5 that the wave was quite distorted, and that the result by the new method was practically unaffected, while the result by the root-mean-square

TABLE II

IRON-LOSS, VOLTMETER METHOD

No.	Transformer	Volts		Total watts	Instrument losses			Core loss (watts)
		Root mean square	Iron-loss meter		*VM* + *WM*	Iron loss *Vm*	Total	
1	*A*............	111.2	110.0	193.6	15.9	27.7	43.6	150.0
2	*B*............	111.2	110.0	189.9	15.9	27.7	43.6	146.3
3	*C*............	111.2	110.0	189.9	15.9	27.7	43.6	146.3
	Sum							442.6
4	*A, B, & C* tested in parallel	112.6	110.0	475.5	9.9	27.7	37.6	437.9
5*	*A, B & C* tested in parallel.....	122.3	110.0	478.0	11.7	27.7	39.4	438.6

ROOT-MEAN-SQUARE VOLTMETER METHOD

No.	Transformer	Root mean square	Iron-loss meter	Total watts	*VM* + *WM*	Iron loss *Vm*	Total	Core loss (watts)
6	*A*............	110.0		162.3	15.5		15.5	146.8
7	*B*............	110.0		158.3	15.5		15.5	142.8
8	*C*............	110.0		158.3	15.5		15.5	142.8
	Sum							432.4
9	*A, B & C* tested in parallel....	110.0		430.5	9.5		9.5	421.0
10*	*A, B & C* tested in parallel....	110.0		387.5	9.5		9.5	378.0

* Voltage wave purposely peaked with inductance.

TABLE III

IRON-LOSS VOLTMETER METHOD

No.	Volts		Core loss	
	Root-mean-square meter	Iron-loss meter		
1	118.5	110.0	185.2	Alternator #1 light load...........Fig. 7
2	115.0	110.0	184.6	Alternator #1 loaded..................
3	115.5	110.0	185.6	Alternator #2 light load...........Fig. 8
4	123.4	110.0	186.2	Alternator #2 loaded.............Fig. 9

ROOT MEAN SQUARE VOLTMETER METHOD

No.	Root-mean-square meter	Iron-loss meter	Core loss	
5	110.0		165.1	Alternator #1 light load...........Fig. 7
6	110.0		171.1	Alternator #1 loaded..................
7	110.0		170.4	Alternator #2 light load...........Fig. 8
8	110.0		157.7	Alternator #2 loaded.............Fig. 9

method was lowered an additional 10 per cent. The additional columns show the intermediate steps used to work out the core loss from the observed readings of volts and total watts input. The wattmeter had no compensating coil to correct for its shunt power and, since the voltmeter and pressure leads of the wattmeter were connected to the terminals of the transformer, corrections had to be made for the instrument loss of the voltmeter and the shunt circuit of the wattmeter. The loss in the iron-loss voltmeter is known from a calibration curve to be 27.7 watts when the instrument reads 110 volts, but to correct for the shunt power in the wattmeter we must use the formula $\frac{E^2}{R}$, where E is the root-mean-square voltage. This makes it clear why the root-mean-square voltmeter reading is also taken.

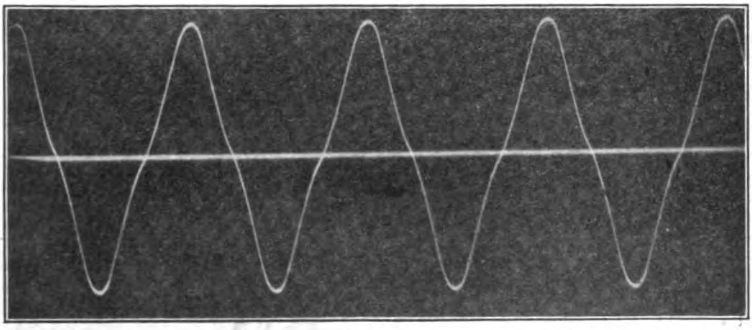


FIG. 7

In this table also it may be seen that the sum of the separate test by the root-mean-square voltmeter method does not check with the sum as tested in parallel, and that the errors of the tests by this method are from 2.1 per cent to 13.8 per cent low.

Table 3 shows some tests made on two different alternators at light load and during heavy low-power-factor load. Both of the alternators in these tests have a peaked wave on no load. Alternator No. 1 is a large, and No. 2 is a small, machine.

Oscillograms of Figs. 7, 8, and 9 show the voltage wave at the terminals of the transformer under the different conditions of test in Table 3. This table shows the results by the new method to agree within less than nine-tenths of one per cent, while the results by the root-means-quare voltmeter method are from 7.7 per cent to 14.9 per cent low and differ among themselves over 8 per cent.

Table 4 shows the effect of errors of frequency on the core losses measured by the two methods. The results of core-loss tests by the new method are practically independent of frequency errors in testing voltage. This means that the core loss at normal frequency and sine voltage can be obtained on a circuit with both frequency and wave-shape errors. It also means that transformer core losses, on a distributing line where the wave-shape is distorted and the frequency unknown, can be tested about as accurately as in a laboratory or at the source of power where the frequency can be accurately adjusted and the voltage wave-shape kept constant by adjusting voltage with the alternator field or a multi-tap transformer.

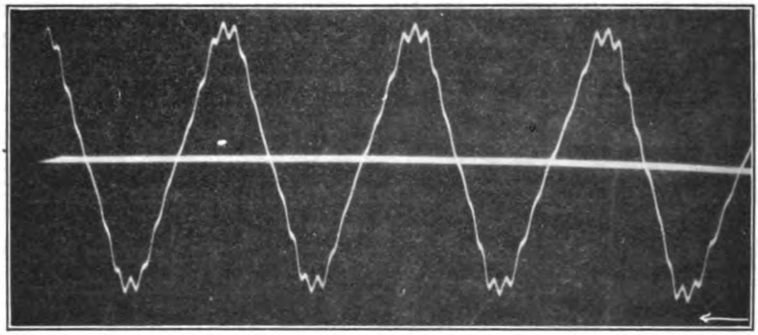


FIG. 8

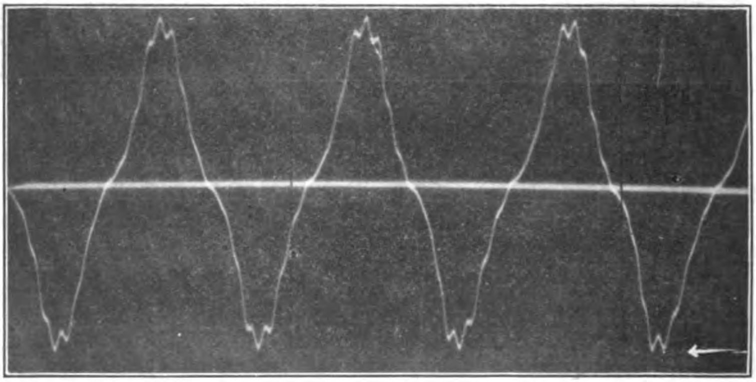


FIG. 9

The tests of Table 4 were made on an alternator with good wave-form, the voltage being adjusted by means of an auto-transformer. The conditions of wave-shape voltage were supposed to be very good and yet it will be noted that the error at 60 cycles by the root-mean-square voltmeter method is as great, due to wave-form distortions, as the error at 53 cycles by the new method.

In closing, it is only fair to speak of the disadvantages of the iron-loss voltmeter and the new method of test. The instrument is necessarily heavier than the ordinary alternating-current voltmeter. The internal losses of the instrument are high and in testing very small transformers the correction for instrument losses is as large as the core loss of the transformer. For high-voltage tests the usual voltage transformer cannot be used on account of the relatively large current taken by the instrument and its poor power-factor. A voltage transformer to be used with the iron-loss voltmeter must be especially designed with heavier copper and low reactance. The instrument can be made direct reading for only one frequency, and, when used on other frequencies, must be used with a calibration curve. These disadvantages are not of great importance as there are generally low-voltage taps on high-voltage transformers, to which the meter can be connected, and there are but few standard frequencies in terms of which tests will be required.

TABLE IV

Iron-loss voltmeter method				Root-mean-square voltmeter method			
Frequency		Core loss		Frequency		Core loss	
Cycles	% error	Watts	% error	Cycles	% error	Watts	% error
68.1	+13.5	201.1	+1.6				
66.4	+10.7	201.0	+1.5	67.1	+11.8	183.1	-7.5
64.5	+7.5	199.3	+0.7	63.3	+5.5	188.9	-4.6
63.7	+6.2	199.5	+0.8	62.1	+3.5	191.6	-3.2
60.0	Normal	198.0	0.0	60.0	Normal	195.6	1.2
59.5	-0.8	197.8	-0.1	57.0	-5.0	202.7	+2.4
59.0	-1.7	197.7	-0.2	54.2	-10.0	208.7	+5.4
56.8	-5.3	196.8	-0.6	52.3	-12.8	211.3	+6.7
55.2	-8.0	197.1	-0.5	50.5	-15.8	218.6	+10.4
53.0	-11.7	195.8	-1.1				
50.5	-15.8	195.1	-1.5				

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A SKETCH OF THE THEORY OF THE ADJUSTABLE-SPEED, SINGLE-PHASE, SHUNT INDUCTION MOTOR

BY F. CREEDY

Up to the present time comparatively little attention has been devoted to single-phase motors having shunt characteristics, as they have been completely overshadowed by the series type, on account of its utility for traction purposes. Nevertheless, these shunt-wound machines have many advantageous features and should have a considerable field of utility. A certain amount of work has been done on them by Milch in this country and by Latour, Fynn and Punga in Europe, and considerable success has been attained in compensating the machine, that is, in raising the power factor to unity.

The object of the present paper is to discuss the variation of the speed of these machines from synchronism. The usual impression, at any rate until recently, has been that the shunt type of machine must necessarily run at a speed in the neighborhood of synchronism. This is not true; theoretically, machines can be built to run at any speed, though in practice there are difficulties in running below synchronism.

First of all, it will be as well to describe briefly the general principles on which all single-phase shunt motors work. All practical machines of this class are developments of the machine shown in Fig. 1, usually known as the Atkinson commutator induction motor. This consists of a slotted stator or primary with a uniform air-gap all round, equipped with a single distributed single-phase winding, and a drum-wound rotor fitted with a commutator, as in a direct-current machine. On the commutator rest four brushes or groups of brushes (in a two-pole machine); the axis of one " pair " of brushes usually lies parallel to that of the primary winding and that of the other perpendicular thereto, but this position is not essential. At standstill the primary coil merely induces a current on the *Y Y* axis (Fig. 1) and hence there is no starting torque. But as the motor speeds up, a current is induced along the *X X* axis which produces a flux along that axis. This current and the flux it produces are nearly in phase with the impressed electromotive force and hence in quadrature with the flux along *Y Y*. Therefore, the flux along *Y Y* (the primary flux) can produce no torque in combination with the current along *X X*. In the neighborhood of synchronism, however, the current along *Y Y*, or the load current, is nearly in phase with the flux along *X X*; hence there will be a torque due to these two in combination.

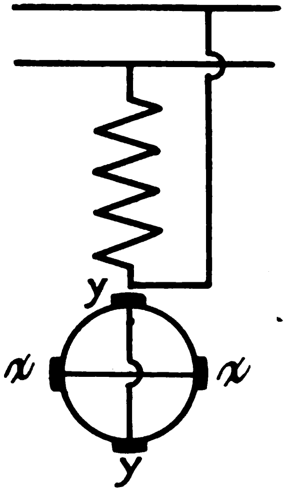


Fig. 1

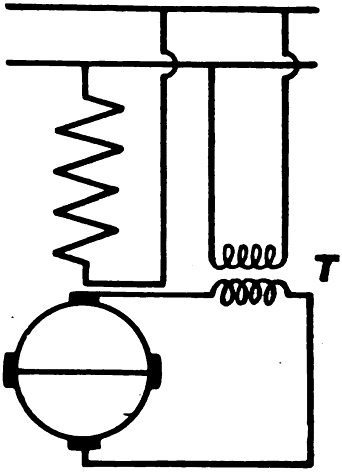


Fig. 2

The flux along *X X* may properly be regarded as the "field" flux of the motor, since it is the flux to which the torque is due. Similarly the current along *Y Y* may be regarded as the armature current, since it has the same functions as this current in a direct-current machine, although, of course, it is induced from the stator, instead of being led directly in as in the continuous-current motor.

The electromotive force on the *X X* axis is due to the movement of the rotor conductors through the primary flux, or flux interlinking the primary circuit. It is, therefore, directly proportional to the speed. The flux along the $X X$ axis, which is determined by this electromotive force in the same manner that the primary flux is determined by the primary electromotive force, is therefore also directly proportional to the speed.

Such a motor reaches its limiting speed when the counter electromotive force, which may be represented by E_2, induced by the field flux (the flux along the axis $X X$) in the armature circuit along the axis $Y Y$ balances the electromotive force E induced therein by the primary flux; or, more exactly, when the vector difference, $E - E_2$, between these two is in quadrature with E_2, the counter electromotive force. This condition is clearly the same as that which limits the speed of the direct-current shunt-wound motor. Hence it would seem that the same methods which are available for varying the speed of the latter should be available here. There are two of these methods, (1) variable voltage control and (2) adjustable field excitation. To apply the first method to the single-phase induction motor we have merely to feed an extra voltage from the line into the $Y Y$ axis, say by means of a transformer as shown in Fig. 2. thereby increasing E. In order that the increased electromotive force E may be balanced by E_2 the motor must clearly run at a higher speed.

It might be thought at first sight that in order to increase E it is merely necessary to increase the primary flux, say by increasing the primary impressed electromotive force. This, however, is a fallacy, because the counter electromotive force E_2 is due to the rotation of the armature in the primary field and is therefore proportional to that field. Hence any variation of the primary field simply varies E and E_2 in the same proportion and the speed consequently remains the same. One may also remark that the secondary field flux becomes effectively equal to the primary flux at synchronous speed, and hence E_2 is effectively equal to E at that speed, which is practically the free running speed of the normal motor.

The above method of speed variation was first discovered by Mr. F. Punga, and is probably on the whole one of the most satisfactory. It was subsequently reinvented by Mr. M. J. Perret, Mr. V. A. Fynn, the writer and others.

A second method, suggested by the writer, is to weaken the field along the $X X$ axis by inserting an inductance or a capacity in the $X X$ circuit, as shown in Fig. 3. An inductance tends to raise the speed and a capacity to lower it. This method is precisely analogous to the speed variation of shunt-wound direct-current motors by field control, except that inductance or capacity must be used instead of resistance. The cause of this is that the circuit $X\ X$ is an almost purely inductive one, and consequently the magnetizing current which flows in it lags practically 90 degrees behind the electromotive force which produces it. It is not desired to alter the phase of the current, or of the flux it produces; hence in order to weaken it an inductance is inserted in the $X\ X$ circuit, and to strengthen it, a capacity. The use of resistance would tend to change the phase of the flux and impair the torque.

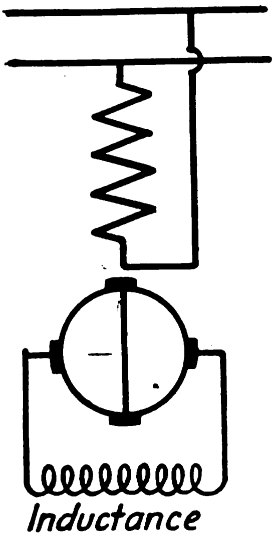


FIG. 3

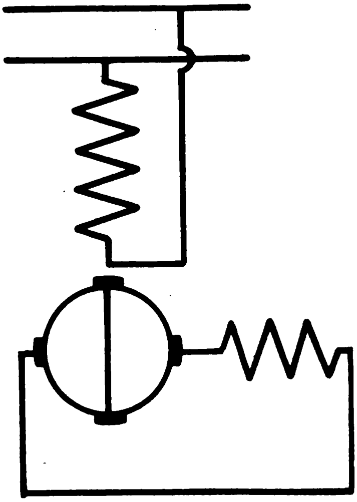


FIG. 4

There is a third method which has no precise analogue in direct-current work. Clearly the flux necessary to balance the electromotive force E_1 induced in the $X\ X$ axis depends on the number of turns in the $X\ X$ circuit. Hence if a coil be put on the stator with its axis parallel to the $X\ X$ axis, and connected in series with the $X\ X$ brushes (see Fig. 4) it will either strengthen or weaken the flux along the $X\ X$ axis, according as the magnetomotive force of this coil opposes or assists the rotor ampere-turns.

These three methods of speed variation are the only radically distinct methods which may be applied to the single-phase induction motor pure and simple. They may, of course, be combined with each other, and with methods of phase compensation and of obtaining a starting torque, in an almost unlimited number of ways, as Messrs. Punga and Fynn have shown in their patent specifications dealing with the subject. Mr. Fynn has also invented a conductive type of machine in which the rotor circuit along the $Y\ Y$ axis is provided with a neutralizing coil, there being along the same axis a coil in shunt to the line, the sole purpose of which is to provide a flux capable of inducing an electromotive force on the $X\ X$ axis. He has also described a number of types in which the $X\ X$ axis is excited by means of a phase transformer, there being only one pair of brushes per pair of poles, but these types of machine do not come within the scope of the present discussion, which is confined to induction types.

Before deciding whether these methods of speed variation are really feasible and, if so, which is the most satisfactory, one must investigate the theory of the subject, as the introduction of the various voltages, etc., might so disturb the phase relations that some or all of the methods might be almost useless.

The clearest manner of describing the properties of an alternating-current motor is usually by means of the circle diagram. It is proposed, therefore, to describe the circle diagrams of the three types of motor described above, and to compare them with the well-known diagram of the ordinary single-phase induction motor.

It will be found that the deduction of these diagrams is quite complicated, as the properties of the motors seem to depend largely upon secondary reactions, which accordingly have to be taken fully into account. The most convenient way to calculate the position of the current circle is to determine three points upon it corresponding to three different speeds.

Discussing the motors in the order given above, the first thing we may remark is that if the electromotive force induced by the primary flux in the $Y\ Y$ axis be E volts and an electromotive force, E_s be introduced, say, by a transformer, the increase of speed will *not* be in the ratio $\frac{E+E_s}{E}$, as it would be in a direct-current motor, because the field flux of the motor is directly proportional to the speed instead of being constant. The change in speed therefore will be proportional to $\sqrt{\frac{E+E_\delta}{E}}$.

In the deduction of the circle diagram, the three most convenient points to take are (1) standstill, (2) synchronous speed and (3) the free running speed. The currents corresponding to these three speeds must be deduced.

The deduction of the current at standstill presents no difficulty. If I_0 = magnetizing current of the machine or the current which the primary winding would take if the secondary were entirely open-circuited, and if I_s = standstill current, then

$$I_s = \frac{I_0}{\sigma},$$

σ being the dispersion coefficient.

The deduction of the other two currents is not so simple. Let E be the electromotive force induced by the primary flux on the $Y\ Y$ axis. Then on the $X\ X$ axis, at a speed k times synchronous speed, there will be an electromotive force k times as great and in quadrature with E; call this E_1. The electromotive force E_1 produces on the $X\ X$ axis a current I_2 proportional to itself. To this current the cross flux is due, and the electromotive force induced by this cross flux on the $X\ X$ axis or, in other words, the electromotive force of self-induction due to this current, is represented in Fig. 5 as $I_2 X$. This cross-flux produces, in its turn, owing to the revolution of the rotor, a back electromotive force on the $Y\ Y$ axis, which again will be k times as great as E_1. This opposes E and is the counter electromotive force of the motor. This is shown in the diagram (Fig. 5) as E_2. The resultant of E and E_2, shown as E_3, is the electromotive force which causes the current to flow through the local impedance of the $Y\ Y$ circuit. The object in drawing this diagram is to get at the electromotive force E_3. The magnitude of this electromotive force may be deduced more conveniently, however, by means of the simplified form of diagram, due to Mr. Punga, shown in Fig. 6. First set out $\overline{O\ E}$ as shown, and then cut off from E a length k times as great to represent E_1. This will be in quadrature with the true E_1 but will serve for the present purpose. Draw in $\overline{E_1\ A}$ equal to $I_2 R$ and $\overline{O\ A}$ equal to $I_2 X$, as before. Cut off from $\overline{O\ A}$ a length k times as great to represent E_2. This vector will have the correct phase relation, as may be seen by reference to Fig. 5, though it is shown for convenience with the opposite direction. Consequently, the electromotive force, E_3, is simply the vector difference between E and E_2. If the phase difference between E and E_2 were neglected, E_3 would be equal to $(1-k^2)\,E$, since $E_1 = k\,E$ and $E_2 = k\,E_1 = k^2\,E$.

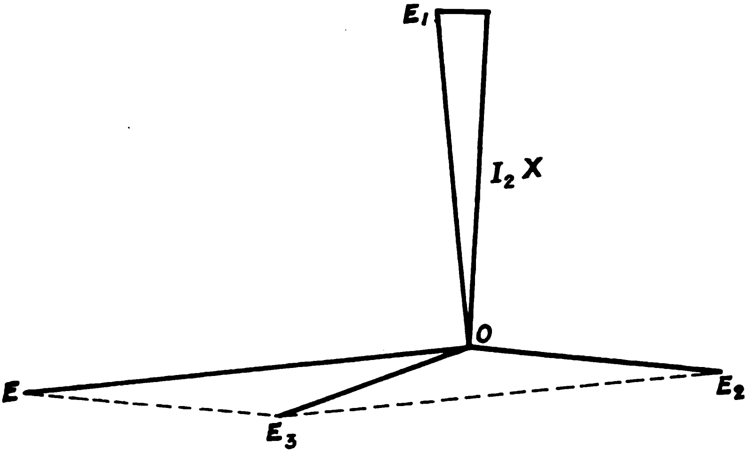


Fig. 5

The action described above, however, is not the only one taking place. In addition to the main flux interlinking both primary and secondary along the $Y\ Y$ axis, there is the secondary leakage flux proportional to the current along $Y\ Y$, and interlinking the secondary only. Clearly all the arguments which apply to the main flux must also apply to this secondary flux. Hence, a diagram may be drawn representing the effects of the leakage flux which will be precisely similar to the one of Fig. 6. Set out E_4, Fig. 7, to represent the electromotive force of self-induction along the $Y\ Y$ axis. Then the flux to which this is due will induce an electromotive force E_5 on the $X\ X$ axis k

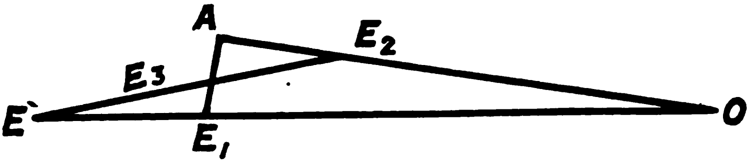


Fig. 6

times as great. Using the same convention as before, cut off from E_4 a length k times as great to represent this. The electromotive force, E_5, on the $X X$ axis will be balanced, as before, by a small supplementary current flowing on that axis, and producing a supplementary flux k times as great as that to which E_4 is due; $O A'$ is the electromotive force induced on the $X X$ axis by this flux. The same flux will induce on the $Y Y$ axis an electromotive force, E_6, k times as great as $O A'$.

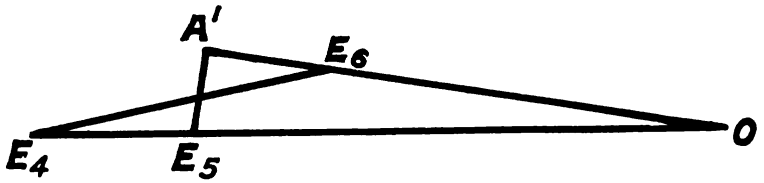


FIG. 7

As before, we may say $E_5 = k E_4$ and $E_6 = k E_5 = k^2 E_4$, by neglecting the slight phase difference between E_4 and E_6. Then, since E_4 is the electromotive force of self-induction due to the current on the $Y Y$ axis, we may say:

In a single-phase induction motor running at a speed of k times synchronism, the electromotive force of self-induction due to a given current along the primary axis will have $(1 - k^2)$ times its value at standstill.

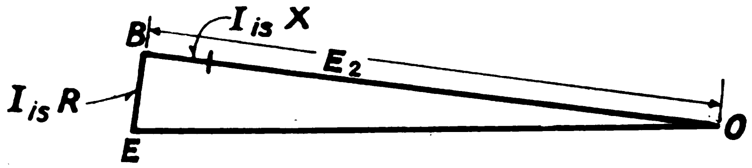


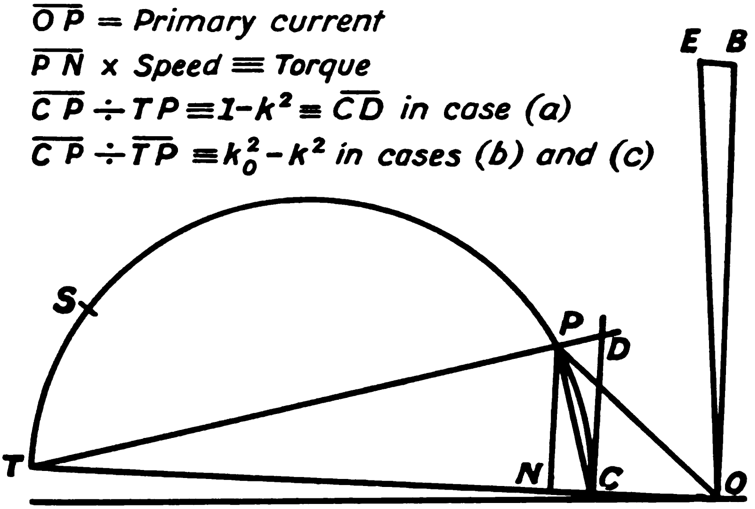
FIG. 8

The slight phase difference above mentioned is strictly a second order effect and will be neglected in future.

In the polyphase induction motor it is well known that the rotor self-induction decreases with increasing speed, owing to the decrease in the frequency. The above investigation shows that a similar effect takes place in the single-phase motor.

With the aid of the foregoing diagrams it is not difficult to establish the circle diagram for the single-phase induction motor. Draw first the triangle of electromotive forces corresponding to synchronous speed (Fig. 8). Here $\overline{O\,E}$ is, as before, the electromotive force induced by the primary flux and $\overline{O\,B}$ is equal to the counter electromotive force E_2 at synchronism.

The impedance of the circuit is $\sqrt{R^2+(1-k^2)^2X^2}$, as shown by the subsidiary diagram. At synchronism, then, when $k = 1$, the reactance vanishes. At any other speed, the current I_1 on the $Y\,Y$ axis may be resolved into two components, I_{1s}, the current at synchronous speed (equals $\frac{\overline{E\,B}}{R}$) and I_1', the remaining or load current; the first component may be considered present at all speeds. $\overline{O\,E}$ is also always present. Now $\overline{O\,E}+\overline{E\,B} = \overline{O\,B}$. and $\overline{O\,E_2} = \overline{O\,B}\times k^2$. Hence the resultant of $\overline{O\,E}$, $\overline{E\,B}$, and $\overline{O\,E_2}$ is $\overline{E_2\,B} = (1-k^2)\times\overline{O\,B}$, as may be easily seen.


$\overline{OP}$ = Primary current
$\overline{PN}$ x Speed ≡ Torque
$\overline{CP} \div TP \equiv 1-k^2 \equiv \overline{CD}$ in case (a)
$\overline{CP} \div \overline{TP} \equiv k_0^2-k^2$ in cases (b) and (c)
E
B
S
P
D
T
N
C
O

Circle - Diagram of (a) the single phase induction motors; (b) the same with speed raised above synchronism by self induction, and (c) the same with speed raised by an auxiliary coil in the X X axis.

FIG. 9

Besides this we have $I_{1s}\,X\,(1-k^2)$ in quadrature with I_{1s}, that is, with $\overline{E\,B}$, and opposite in phase to $\overline{O\,B}$; this is a constant quantity at a given speed; $I_1'\,R$; $I_1'\,X\,(1-k^2)$.

The resultant electromotive force, then, which may be regarded as producing the flow of the current is $(\overline{O\,B}-I_{1s}\,X)\,(1-k^2)$ which may be called $E_7\,(1-k^2)$.

Hence,

$$I_1' = \frac{E_7\,(1-k^2)}{\sqrt{R^2+(1-k^2)^2\,X^2}} = \frac{E_7}{\sqrt{\left(\frac{R}{1-k^2}\right)^2 + X^2}}$$

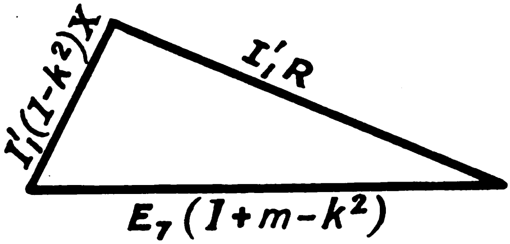


FIG. 10

This is the equation for the current in a circuit of variable resistance and constant self-induction. It is well known that under such circumstances, if the electromotive force is constant, the current vector travels on a circle, and consequently it must do so here.

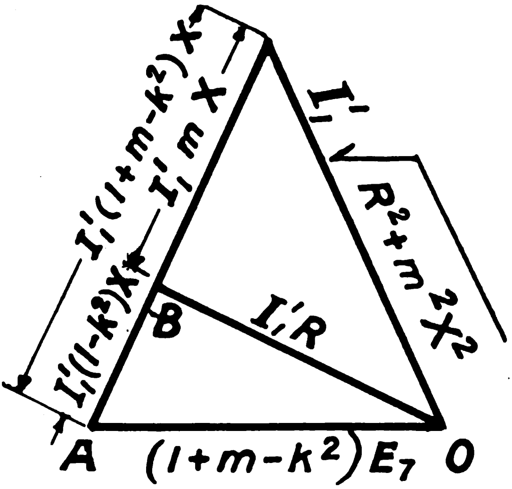


FIG. 11

Fig. 9 shows the complete diagram, the electromotive force triangle $O\,E\,B$ being shown vertical so as to bring the circle into a more customary place.

From the foregoing it is easy to investigate the value of I_1' in the variable-speed motor, as I_{1s} will be the same as before.

There is now another electromotive force $E_8 = m\,E_7$. Assuming that it is in phase with E_7, we get $(1 + m - k^2)\,E_7$ for the resultant electromotive force causing the current to flow. The three sides of the triangle of electromotive forces will then be as indicated by Fig. 10.

To prove that I_1' still moves on a circle, $I_1'\,(1 - k^2)\,X$ may be written $I_1'\,(1 + m - k^2)\,X - I_1'\,m\,X$, and this results in the diagram Fig. 11, which is self-explanatory.

Since the angle $\overline{O\,B\,C}$ is a right angle, $\tan\theta = \dfrac{R}{m\,X}$ and hence θ is constant.

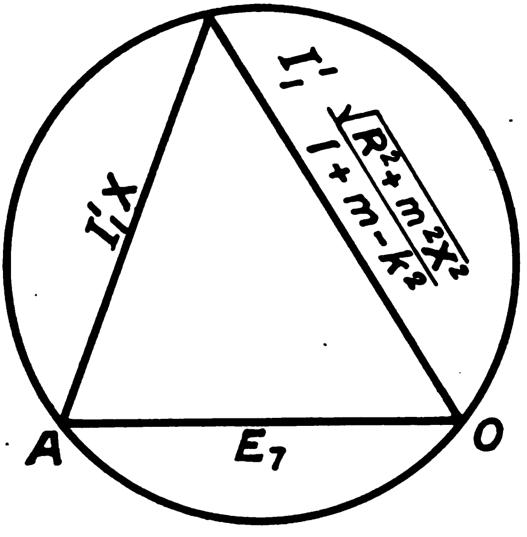


Fig. 12

Since both $\overline{O\,A}$ and $\overline{A\,C}$ contain as a factor the quantity $(1 + m - k^2)$, dividing all three sides by this will give the somewhat simpler values of Fig. 12.

Since $\overline{O\,A}$ and θ are constant while the ratio

$$\frac{\overline{A\,C}}{\overline{O\,C}} = \frac{(1 + m - k^2)\,X}{\sqrt{R^2 + (m\,X)^2}},$$

and therefore varies with the speed, it is clear that the point C must describe a circle. Since $\overline{O\,C}$ is proportional to the load current, it is evident that in the motor under consideration the secondary current vector moves on a circle.

The magnitude of the load current I_1' is given, at any speed, by the equation

$$I_1' = \frac{E_7\,(1+m-k^2)}{\sqrt{R^2+(1-k^2)^2\,X^2}}$$

and when $k = 1$, then $I_1' = \frac{m\,E_7}{R}$; or, at synchronous speed the secondary load current is equal to the electromotive force fed in through the commutator, divided by the secondary resistance. The current at synchronism in this motor, therefore, is equal to the current taken by a single-phase induction motor at synchronous speed, together with a current E_8/R in phase with the electromotive force E_5.

The next step is to calculate the current at the free running speed. This speed occurs when the current on the $Y\,Y$ axis is in quadrature with the counter electromotive force E_2.

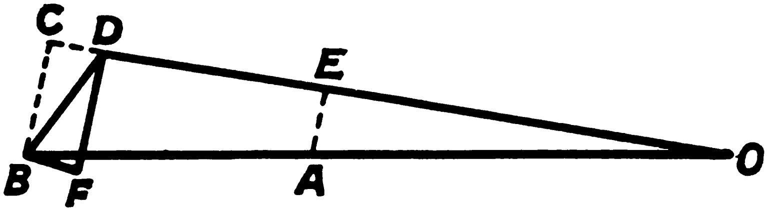


FIG. 13

Fig. 13 is a new diagram in which $\overline{O\,A} = E$, the electromotive force induced on the $Y\,Y$ axis by the primary flux. Then the triangle $O\,A\,E$ represents the conditions at synchronous speed. This triangle, as shown above, is identical with the electromotive force triangle for the $X\,X$ axis, and hence $\overline{A\,E}$ is equal to $I_2\,R$ and is in quadrature with $\overline{O\,E}$. If, however, an electromotive force $\overline{A\,B}$ be added, making a total of $\overline{O\,B}$, then, at a suitable speed, the counter electromotive force of the motor will rise to $\overline{O\,C}$, and $\overline{B\,C}$ will equal $\frac{\overline{O\,B}}{\overline{O\,A}} \times \overline{A\,E} = k^2.\ \overline{A\,E}$, since the speed is only proportional to the square root of the voltage. But it is only at synchronism that the rotor current is in phase with the vector difference between the impressed and the counter electromotive forces. At the speed now under consideration the self-induction along the $Y\,Y$ axis comes into play. We saw that at the speed $k\times$synchronism the inductance along this axis was $(1-k^2)\,X$, if X is its value at standstill. Above synchronism, accordingly, it will be negative, or in other words, have the effect of a capacity. Hence in the diagram Fig. 13, in which $\overline{B\,D}$ is the vector difference between the impressed and the counter electromotive forces, $\overline{D\,F} = I_1\,R$ and $\overline{B\,F} = (1-k^2)\,I_1\,X$.

If this diagram is to correspond to the free speed, $\overline{D\,F}$ must be perpendicular to $\overline{O\,D}$, since it is in phase with I_1, and in order that the torque may vanish I_1 must be in quadrature with $\overline{O\,D}$; $\overline{B\,F}$ is perpendicular to $\overline{D\,F}$ and therefore must be parallel to $\overline{O\,D}$; $\overline{B\,C}$, as shown above, is also perpendicular to $\overline{O\,D}$. Hence $B\,C\,D\,F$ is a parallelogram and $I_1\,R = \overline{D\,F} = \overline{B\,C} = k^2\,\overline{A\,E}$. Hence the secondary current on the $Y\,Y$ axis at the free speed has the same phase and is k^2 times as great as at synchronism in the normal single-phase induction motor. It may be noted also that the motor does not quite attain the free speed corresponding to the impressed electromotive force. If this method of speed variation is used to lower the speed, the motor evidently will rise somewhat above its theoretical speed on no load.

To sum up the results, having calculated three points on the circle diagram corresponding to this motor:

The current at standstill will be

$$I_s = \frac{I_0}{\sigma}$$

where I_0 = magnetizing current of the machine or the current which the primary would take if the secondary were entirely open-circuited, and σ = dispersion coefficient.

The current at synchronous speed $= 2\,I_0 + \frac{E_s}{R}$. The magnetizing current I_0, of course, lags nearly 90 degrees behind the impressed electromotive force e and $\frac{E_s}{R}$ is in phase with it; therefore the addition must be made vectorially.

The secondary current at the free speed was $k^2\,I_0$, and adding the primary magnetizing current, the primary current at the free speed $= (1+k^2)\,I_0$.

Fig. 14 shows the circle diagram drawn through the three points calculated; here $\overline{OA}$ is the standstill current, $\overline{OB}$ that at synchronous speed, and $\overline{OC}$ that at the free speed, $\overline{DP}$ being the secondary current.

The torque will clearly be proportional to the product of the secondary current $\overline{DP}$ and the flux along the XX axis, multiplied by the cosine of the angle between them. This flux, like the counter electromotive force, is nearly in phase with the primary electromotive force, differing from it by a small angle due to the secondary resistance. It is shown in the diagram as $\overline{OF}$ and is, of course, proportional to the speed. Hence if a line $\overline{DG}$ be drawn perpendicular to $\overline{OF}$ and passing through $\overline{OD}$, we may say that the torque is proportional to $\overline{PN} \times K$, the same construction as in the ordinary single-phase induction motor.

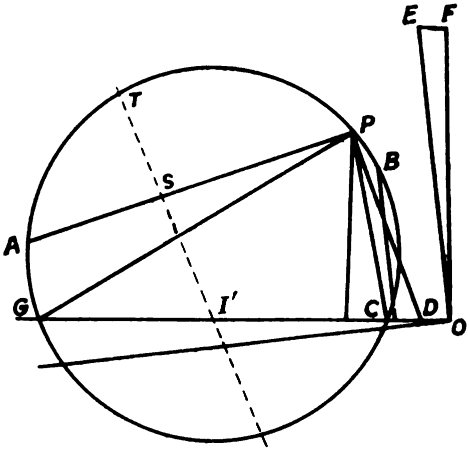


FIG. 14

It is easy to show, morever, that $\overline{CP} \div \overline{AP}$ is approximately equal to $k_0^2 - k^2$ where k_0 is the free running speed ÷ synchronous speed.

By setting out a line $\overline{ST}$ so that the angle ART is equal to APC, we get $k_0^2 - k^2$ as the intercept $\overline{QR}$ cut off on this line by the line $\overline{AP}$. $\overline{ST}$ will naturally be parallel to the tangent to the circle at C.

This is all we need know of the diagram in order to appreciate the characteristics of the motor.

Fig. 15 gives diagrams of three methods of connecting a commutator motor: (*a*) as a plain single-phase commutator induction motor with two pairs of short-circuited brushes; (*b*) as a single-phase induction motor with the speed raised above synchronism by Punga's method; (*c*) as a two-phase induction motor with two pairs of brushes short-circuited.

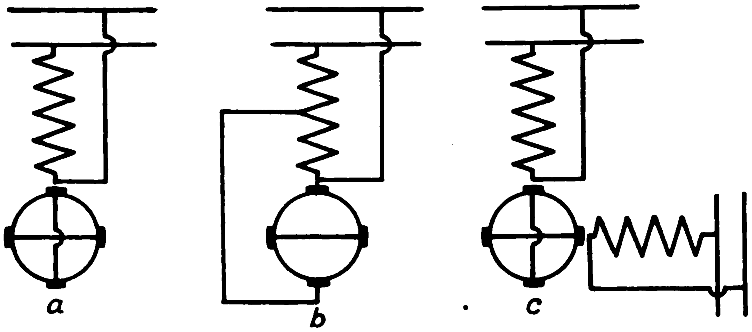


FIG. 15

In Fig. 16, 1 is the well-known circle diagram of the single-phase induction motor; 2 is the better-known diagram of the two-phase motor, drawn out so that the current vector represents the total current; that is, the arithmetical sum of the currents in the two phases. This is the only fair way of making a comparison. Under these circumstances the total no-load current of the polyphase motor will be the same as that of the single-phase machine, but the total short-circuit current will be doubled, giving the

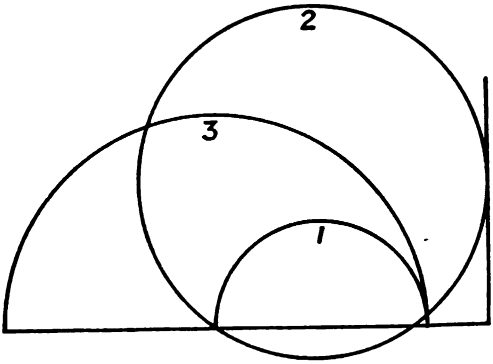


FIG. 16

diagram as shown. Diagram 3 is the circle diagram of the new motor. The no-load current is rather greater than that of the single-phase motor, while the short-circuit current is the same. The current at synchronous speed, $\frac{E_s}{R}$, is shown in the diagram.

It is clear that the shunt motor excels both the single-phase and the polyphase motors enormously as regards both overload capacity and power-factor. Moreover the overload capacity may be adjusted at the pleasure of the designer without changing the flux. In fact, this motor is more closely analogous to the direct-current motor in that the output is not limited by the break-down point but by heating and sparking. The power-factor also may, of course, be controlled by the same means as the break-down point viz. by varying E_b.

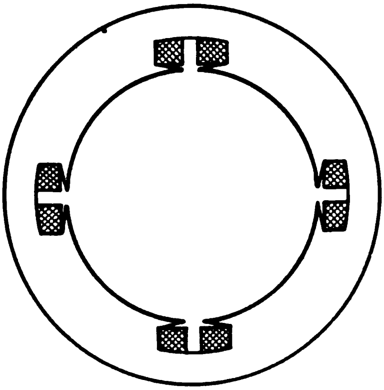


Fig. 17

The principal lesson which the comparison of circle diagrams teaches, then, is that in this type of motor the power-factor and overload capacity are independent of the leakage coefficient, which determines both in the polyphase motor and the ordinary single-phase induction motor. This gives the designer a great deal of freedom in the choice of the number of slots, air-gap, etc. In fact, in the writer's opinion, it is probable that a motor of this type might be made to operate fairly well if built with salient poles, somewhat as shown in Fig. 17. Such a motor, no doubt, would be somewhat heavier than the usual distributed-winding type, and would probably encounter a good deal of prejudice at first. The dispersion coefficient would undoubtedly be very high, say 0.25, but, as already shown, this affects neither the overload capacity nor the power-factor.

It is true that the theory given above does not take account of the primary leakage in detail, but it may be pointed out that if the primary current leads, then the electromotive force of self-induction due to this current tends to increase the primary counter electromotive force; that is, the electromotive force to be balanced by the main or air-gap flux will be greater than the impressed electromotive force. It can very easily be arranged to make the primary current lead, so primary leakage need not cause trouble.

A good many difficulties would, no doubt, have to be met before such a radical departure from present-day practice could be successfully introduced. However, such a motor would be so simple and robust, almost comparing with a direct-current machine, that the introduction would probably be well worth the effort. It would also present possibilities of standardization probably excelling those offered by any other type. To adapt a given frame for different speeds, frequencies (within limits), voltages or horse-powers (also within limits), all one has to do is to change the coils, since the armature is standard, not being connected to the mains, and the speed can be changed without changing the number of stator poles. However, the salient-pole machine is at present a speculation, as one naturally would try a machine with a distributed winding, first it would probably be worth while, even in a standard machine in which speed variation is not required, to run the machine at, say, 7 per cent or 8 per cent above synchronism on account of the very much increased power-factor and overload capacity thereby obtained. Such a machine would then drop to about synchronous speed at full load, and one should get improved commutation as well as the other advantages mentioned. All this holds in the case where the motor runs above synchronism.

If this method of speed variation be employed to reduce the speed, very different results are obtained. In this case, the electromotive force E_v is reversed, and the circle is as shown in Fig. 18, where $\overline{OC}$ = no load current, $\overline{OA}$ = short-circuit current, and $\overline{OB}$ = current at synchronous speed. In this diagram the motor part (that above $\overline{AC}$) almost disappears. Hence the machine will not carry any load, and the conclusion is that this method is not suited for reducing the speed below synchronism.

THE USE OF SELF-INDUCTION

We now come to the second type of motor in which the speed is varied by inserting self-induction in the " field " or $X\ X$ circuit. A simple modification of the diagram used before will serve to elucidate the properties of this type of motor. In this diagram (Fig. 19) we have E as before, but the speed is now above synchronism. Hence E_1, the voltage on the $X\ X$ axis, will be greater than E, as shown. This electromotive force is balanced, as before, by $I_2\ R$ and $I_2\ (X_1+X_0+X)$, R being the secondary resistance and X_0+X+X_1 the total secondary reactance. This must now be divided into two parts, the reactance X_0+X, due to the flux along $X\ X$ and the reactance X_1 which is external to the motor. The counter electromotive force E_2 will, of course, be k times $I_2\ (X_0+X)$ only. This is shown in the diagram, and the free speed will occur as before when the current on the $Y\ Y$ axis is in quadrature with E_2.

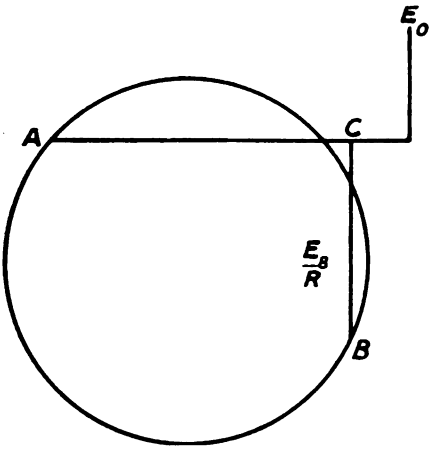


FIG. 18

Now, following through the various reactions due to the leakage flux along the $Y\ Y$ axis in exactly the same way as before, a diagram quite similar to Fig. 19 may be derived and it will be found that the reactance is balanced exactly at the free speed of the motor. Hence the current on the $Y\ Y$ axis must be in phase with the vector difference between E and E_2 at that speed. Thus the relations of transformer electromotive force, counter electromotive force, and current on the $Y\ Y$ axis are just the same in the new motor at its free speed, as in the ordinary single-phase induction motor. The current, therefore, will have the same value; that is, the current on the $Y\,Y$ axis will be equal to that which exists on the $X\,X$ axis at synchronous speed. The diagram then is identical with that of the single-phase induction motor save that the free speed is different.

If k_0 be the ratio of free speed to synchronous speed, then the construction which in the ordinary motor gives $(1-k^2)$ will give $(k_0^2-k^2)$. The torque characteristics, overload capacity, etc., will be just as in the ordinary induction motor. Hence this machine will work best when compensated.

A capacity connected across the $X\,X$ circuit would clearly be just as effective in lowering the speed, but it is not much use going into the theory of this in detail, as the condenser required for such a method of speed regulation would be far too costly for practical use.

One caution is very important when testing these motors, or, indeed, any type of commutator induction motor. The presence of four brushes on the commutator, opposite pairs being joined together, gives an opportunity for the circuit along $X\,X$ to differ in resistance from that along $Y\,Y$. If the $X\,X$ circuit has a high resistance, say, double that of the $Y\,Y$ circuit, then the difference between E and E_2 at synchronous speed will be double what it would be if the two resistances were equal; hence the no-load current on the $Y\,Y$ axis will be doubled and the power-factor of the motor correspondingly reduced. It is very important, therefore, to keep the resistance of the $X\,X$ circuit down, or very unfavorable conclusions may be drawn as to the power-factor of these machines.

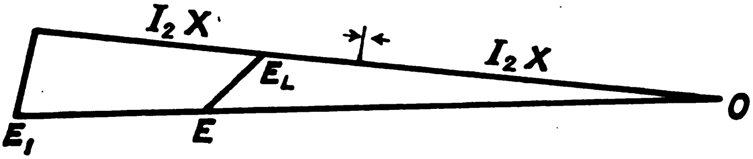


FIG. 19

We now come to the third type of motor, in which there is a coil parallel to the $X\,X$ circuit and connected in series therewith. Fig. 20 is the diagram for this case; it is quite similar to those already drawn. The voltage E_1 is larger than E, as before, because the speed is assumed to be greater than synchronism. This is balanced by $\overline{O\,E}$, the electromotive force of self-induction due to the flux along $X X$ interlinking the whole circuit along that axis, both on the stator and the rotor. $\overline{O E''}$ is the electromotive force induced by the field flux in that portion of the $X X$ circuit which lies on the armature alone; of course, $\frac{E''}{E'} = \frac{T}{T_1}$, if T is the number of turns on the armature and T_1 that on the armature and auxiliary coil combined. The counter electromotive force, E_2, will be k times E''. The free speed occurs as before when $E - E_2$ is perpendicular to E_2.

An examination of the subsidiary diagram for the leakage flux will show that the self-induction in the $Y Y$ axis is also balanced at the free speed, since the diagram is identical with the one just given. Hence, as in the last type of motor considered, the current on the $Y Y$ axis at the free speed is equal to the stator magnetizing current, and, consequently, the stator no-load current is equal to double this latter, just as in the ordinary single-phase induction motor. The circle diagram also is identical with that of the induction motor, as with the last type discussed, save that the speed construction gives $(k_0^2 - k^2)$ instead of $(1 - k^2)$.

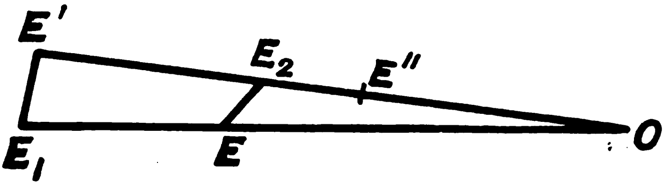


FIG. 20

The present method supplies probably the best method of lowering the speed, but its scope is limited by the following considerations.

Suppose it is desired to reduce the speed of a motor to halt of the synchronous speed. In order to do this, the "field" flux must be twice that at synchronous speed. But in order to get twice the flux in the $X X$ axis, one-half the number of turns would be required, even if the voltage induced in the $X X$ circuit remained constant at all speeds. Since it is halved at half speed, only one-quarter of the number of turns required at synchronism will be needed to give double the flux, and since the required ampere-turns are twice those at synchronism, the current must be eight times that at synchronism. The current in the $X X$ axis is proportional to the inverse cube of the speed. The decrease of speed obtainable by this method is limited, therefore, by the abnormal increase in the current on the $X X$ axis.

Unless the $X X$ brush gear is specially designed, probably a drop of 20 per cent in speed, which will double the current on the $X X$ axis, is as much as will be possible.

The foregoing investigation indicates that there is no thoroughly practical method of lowering the speed, although there are several good ways of raising it.

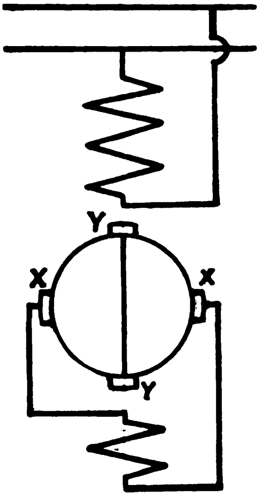


Fig. 21

Before leaving the theory of these motors, it will be convenient to consider briefly the theory of phase compensation as applied to the single-phase induction motor, since in many cases phase compensation produces a great improvement. A diagram of connections of a compensated motor is shown in Fig. 21.

In order to avoid constructing an entirely new theory of this motor, the best way to consider it will be as follows: Add along the $X X$ axis an electromotive force, E_0^1, of constant value and in phase with the impressed electromotive force. Here E'_0 may be regarded as superposed on the others and as producing its own effects undisturbed by any of the other actions going on in the motor. This will give rise on the $Y Y$ axis to another electromotive force in quadrature with it and proportional to the speed, and this second electromotive force will lead E' by 90 degrees if the compensating coil be correctly connected. The current due to this electromotive force will be determined by the resistance and inductance of the Y Y circuit in the usual manner; in fact, this current will be

$$I_3 = \frac{k\, E_c^1}{\sqrt{R^2 + (1 - k^2)^2\, X^2}}.$$

It is easily proved that if a constant electromotive force be applied to a circuit of constant resistance and variable self-induction, the current vector will move on a circle, as in Fig. 22. If it were not for the factor k in the numerator, I_3 would clearly flow in such a circuit, the resistance being R and the inductance $(1-k^2)\ X$, and therefore varying with the speed, but in the present case the values obtained from such a circle have to be multiplied by k as shown by the equation, giving the diagram shown in Fig. 23. This current then has to be added to the ordinary induction-motor current to obtain the current in the compensated motor, and the diagram of Fig. 24 is obtained. The very simple theory on which this diagram is based is also the basis of the treatment of the ordinary single-phase induction motor and will be found in accord with the more complex theories which have been published from time to time, in which the compensated motor is treated independently.

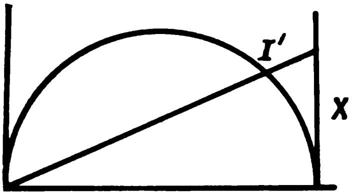


FIG. 22

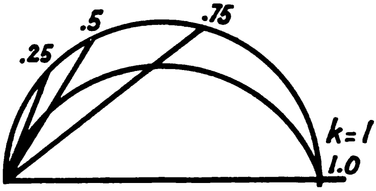


FIG. 23

The very considerable increase in the overload capacity is clearly shown by Fig. 24: it usually amounts to about 40 per cent. The locus of the current vector is now not strictly a circle but for the purpose of calculating the overload capacity it may conveniently be assumed to be such.

In order to get satisfactory compensation, there must be a current on the Y Y axis at synchronism capable of producing a flux along that axis sufficient to balance the primary electromotive force, thereby rendering the primary magnetizing current unnecessary; therefore, the normal current on the $Y\,Y$ axis must be reversed, and in order to do this, a current of twice the magnitude and of opposite direction must be superposed on it.

At synchronism the compensating current on the $Y\,Y$ axis is $\frac{E^1}{R^1}$, as shown above, E^1 being the compensating electromotive force. For good compensation, $\frac{E^1}{R} = 2\,I_0$, or $E^1 = 2\,I_0\,R$. This furnishes a means of getting an idea of what the compensating electromotive force should be, but the best value can really only be found by experience.

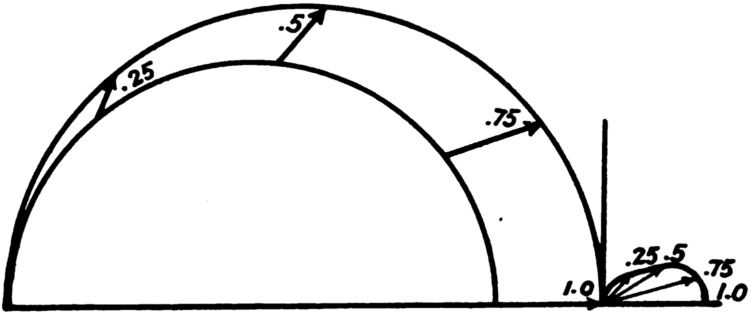


FIG. 24

COMMUTATION

The commutation of the various types of motor described above must be discussed before one can decide that they are entirely feasible. Consider first the commutating coils under the $Y\,Y$ brushes. There will be three electromotive forces induced in these: the reactance voltage, proportional to and in phase with the current; the "electromotive force of rotation" or that induced by the commutating coil cutting the flux along the $Y\,Y$ axis, and the "transformer electromotive force" or electromotive force induced by the alternation of the flux along the $X\,X$ axis, which flux clearly threads the commutating coil. The flux along the $Y\,Y$ axis also induces an electromotive force of rotation on the $X\,X$ axis similar to that induced in the commutating coil. This electromotive force, obviously, will differ from that induced in the commutating coil merely by the ratio of transformation between the rotor and the commutating coil.

The flux along the *X X* axis induces a similar transformer electromotive force in the *X X* circuit, likewise differing from that induced in the commutating coil merely by the transformation ratio. The two electromotive forces induced in the *X X* circuit balance one another at every speed, of course, and it therefore follows that the similar electromotive forces induced in the commutating coil do so also. This leaves only the reactance voltage, which exists also in the direct-current machine.

We may, therefore, say that as long as the *X X* brushes remain short-circuited, the commutation under the *Y Y* brushes is the same as that of a direct-current machine. Now the *Y Y* brushes carry the main current while the *X X* brushes only carry a small magnetizing current, so that when speed variation is obtained by voltage control we may expect good commutation. If, however, extra turns or a reactance coil be inserted between the *X X* brushes, the difference between electromotive force of rotation and transformer electromotive force will be equal to the actual external voltage between the *X X* brushes multiplied by the ratio of transformation between rotor and commutating coil.

Now, consider the commutating coils under the *X X* brushes. The axis of these coils is parallel to the *Y Y* axis, just as the axis of the coils under the *Y Y* brushes was parallel to the *X X* axis. The " electromotive force of rotation " and transformer electromotive force induced in these coils then correspond to the induced and counter electromotive force, E and E_2, discussed above. These, we saw, approximately balanced one another at the free speed in the simple induction motor. Hence, it may be considered that in the simple commutator induction motor, the commutation under the *X X* brushes is like that of a direct-current motor at and about the free speed. If, however, an external electromotive force, E_8 be inserted in the *Y Y* axis, say, such as to increase the induced electromotive force. E, then the counter electromotive force $E_2 = E + E_8$ or $E_2 - E = E_8$. As before, the resultant of the transformer and rotation electromotive force in the commutating coil on the *X X* axis is equal to $E_2 - E = E_8$ multiplied by the transformation ratio between the rotor and the commutating coil. We may, therefore, generalize from the statement made above as follows:

The resultant induced electromotive force (excluding reactance voltage) in the commutating coils under two opposite brushes of a commutator induction motor is equal, near the free speed, to the electromotive force between the alternate pair of brushes multiplied by the transformation ratio between the rotor and the commutating coil; hence, a potential difference between any two opposite brushes will tend to make the alternate pair spark. To obtain a given rise of speed, therefore, with the least sparking voltage, one should have equal potential differences between both pairs of brushes.

The foregoing theory cannot be claimed to have any great elegance or high degree of perfection. It represents merely the writer's attempt to get a clear understanding of this type of motor so as to be able to design it with some certainty, and it is hoped will be received as such.

EXPERIMENTAL RESULTS

A considerable amount of experimental work has already been done on adjustable-speed single-phase motors, both in this country and abroad, and there can be little doubt, I think, that a commercial machine will shortly be placed on the market either in Europe or here, or perhaps both. I propose to describe herein a number of tests which are at present at my disposal and to indicate briefly in what directions further tests are desirable.

EXPERIMENTS OF MR. F. PUNGA AND THE AUTHOR

Motor No. 1. The first motor built was a small machine giving 1.25 horse-power on a circuit of 40 cycles and 220 volts. It was arranged as shown in the diagram, Fig. 4, having a cross winding divided into two parts so that three speeds were available; viz., synchronism and two speeds above synchronism. A compensating coil was also employed on this motor. The results of the tests on this machine for the three different speeds are shown in Fig. 25. It will be evident that the power-factor is very high, the slip from no load to full load considerable, and the efficiency comparatively low although tolerably good for so small a motor of this type. Constant compensation was employed at all speeds and, as the charts show, the power-factor remained very nearly constant, falling off slightly at the higher speeds. The commutation was thoroughly satisfactory at all speeds as, of course, it should be in so small a motor.

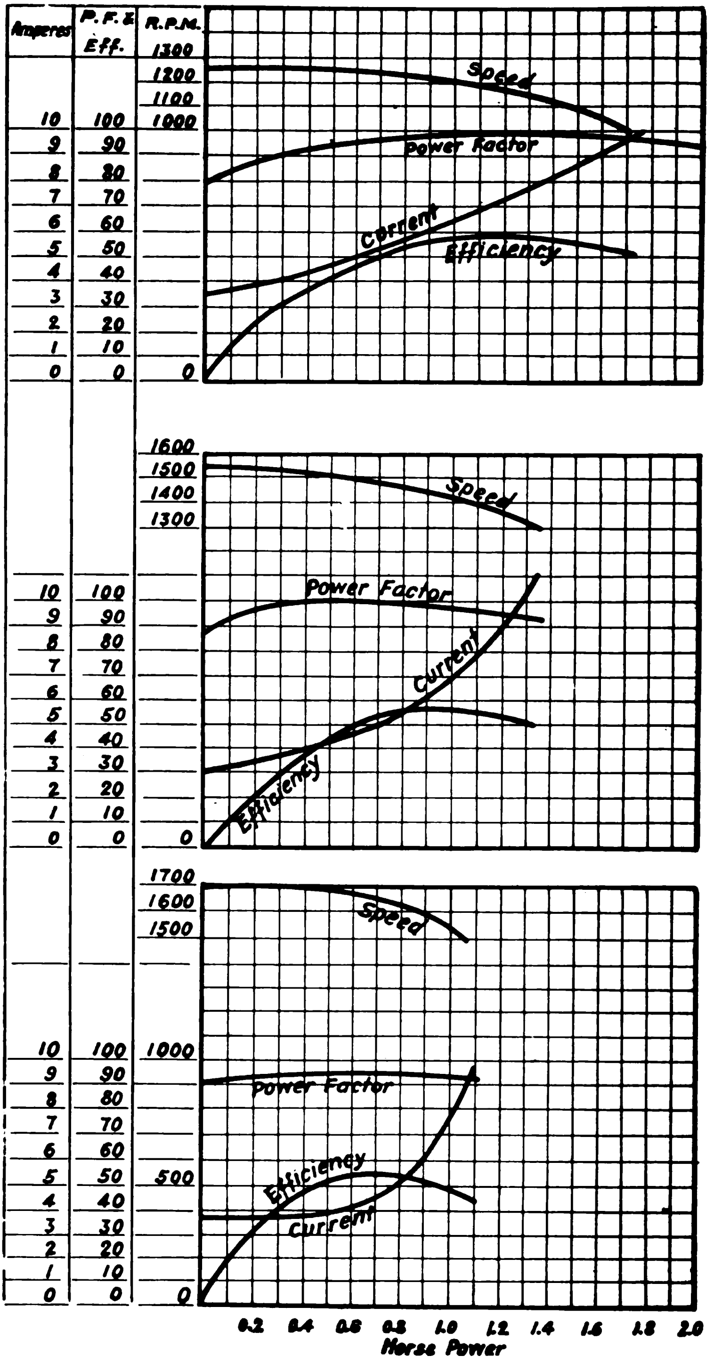

Amperes
P.F. & Eff.
R.P.M.
1300
1200
1100
1000
10
9
8
7
6
5
4
3
2
1
0
100
90
80
70
60
50
40
30
20
10
0
Speed
Power Factor
Current
Efficiency
1600
1500
1400
1300
Speed
Power Factor
Current
Efficiency
1700
1600
1500
1000
500
Speed
Power Factor
Efficiency
Current
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Horse Power

FIG. 25

Below synchronism satisfactory results were not obtained, as a totally different compensating voltage would have been required. This could not be conveniently arranged for experimentally at the time. The results obtained by Dr. Alfred Fraenckel, however, given below, show that a considerable reduction in speed below synchronism is possible by suitable arrangements. In fact, his results below synchronism are superior to any that I have yet been able to obtain.

The results obtained on motor No. 1 were considered sufficiently satisfactory to justify further experiment and one or two motors were even built commercially for driving small printing presses and the like. These had a speed range of about 1.5 to 1.0 and a capacity about the same as that of the experimental motor.

Motor No. 2. This was a 5 horse-power machine operating at 200 volts and 50 cycles. It was arranged to obtain some data on the method of varying the speed by the use of self-induction. Some speed curves on this motor are given in Fig. 26. It was found that the use of inductance in the field circuit diminished the power-factor; hence variable compensation should be arranged for when it is desired to adjust the speed of a motor by this means.

The commutation of this motor was satisfactory at all loads and speeds, but the full-load efficiency averaged only 63 per cent to 65 per cent. The slip between no load and full load was high.

In spite of the comparatively poor results of tests on this motor the writer believes that the use of inductance in conjunction with a small adjustable compensating transformer offers one of the most promising means of varying the speed at our disposal. The two may be combined so that movement of the lever of the field-regulating controller simultaneously varies the inductance and adjusts the compensation. In this case the controller will be hardly more complicated than the regulating rheostat of a direct-current motor.

Motor No. 3. On this third motor a considerable number of tests have been made. This was a four-pole machine operating at 400 volts and 25 cycles. Arrangements were made for adjustable compensation in case it was needed, but it was finally found that very satisfactory results could be obtained without it. Arrangements were also made to try the method of speed variation both by armature voltage control and by field variation. The curves in Fig. 27 show the different speed curves and those in Fig. 28 the power-factor at one-half three-quarters and full load. A very wide speed range was covered, *viz.*, about 2½ to 1 and it may be noted that the high slip characteristic of the older motors has been eliminated.

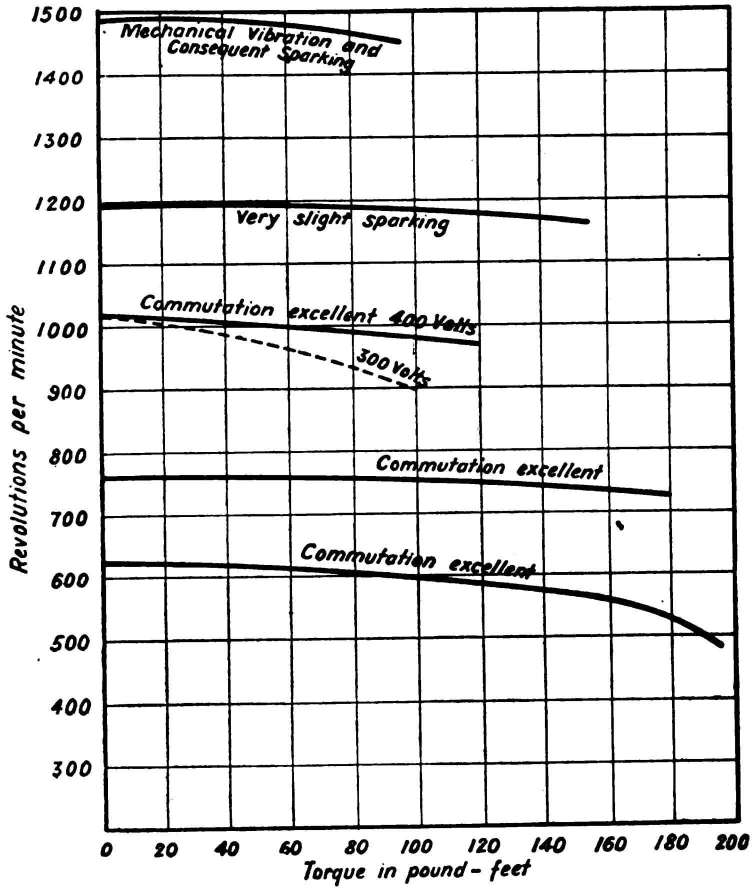


FIG. 26

The upper limit to the speed was set in this case by the circumferential speed of the commutator, which, above 1400 rev. per min., gave rise to a good deal of vibration and consequent sparking. The lower limit was due to the abnormal increase of the current in the cross or magnetizing brushes which, below about 600 rev. per min., began to give rise to excessive heating and severe sparking under these brushes. A further reduction of the speed was also impractical by another cause. Below synchronism the ampere-turns of the auxiliary cross winding oppose those of the rotor winding; hence the field circuit composed of these two in series, has a comparatively low inductance. The correctness of the phase of the field flux depends upon the reactance of the field circuit being largely in excess of its resistance. At very low speeds, this will no longer be the case and the torque will begin to fall off.

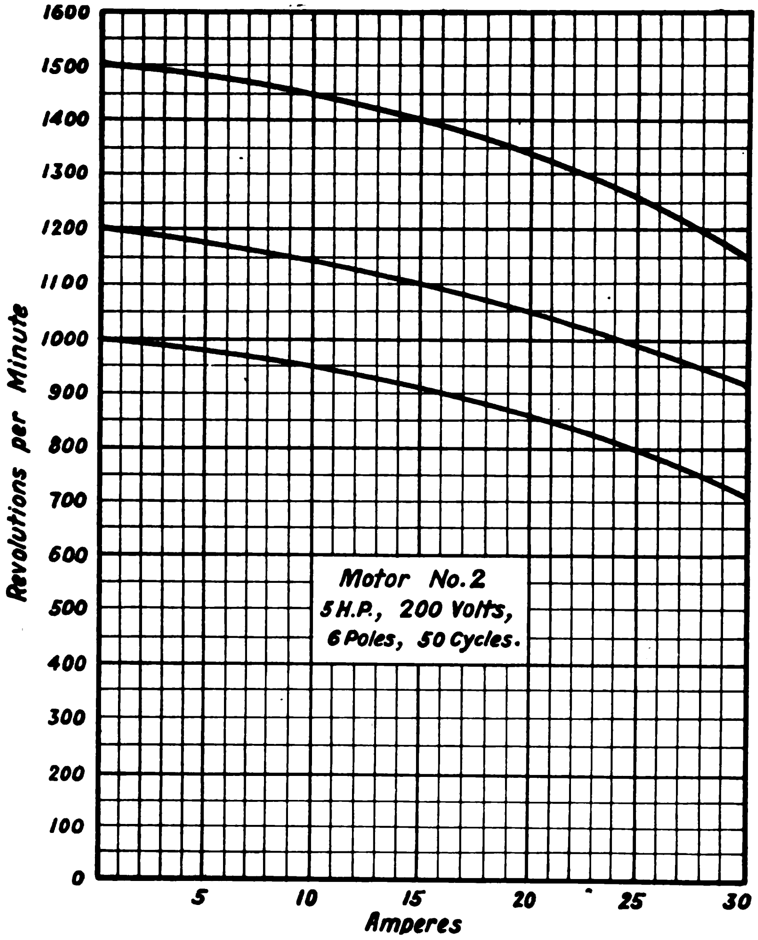


FIG. 27

The speeds between 600 and 1000 rev. per min. were obtained by field regulation while those above 1000 rev. per min. were obtained by using armature voltage control in addition. A constant compensation was used for all speeds except that of 600 rev. per min. where it was experimentally inconvenient to employ compensation. This was adjusted so as to give somewhat less than the maximum power-factor as it was found that at high speeds the compensating voltage applied to the exciting brushes produced quite a noticeable effect on the commutation under the armature or load brushes. Hence, only an amount of compensation sufficient to give the results of Fig. 28 was employed. The

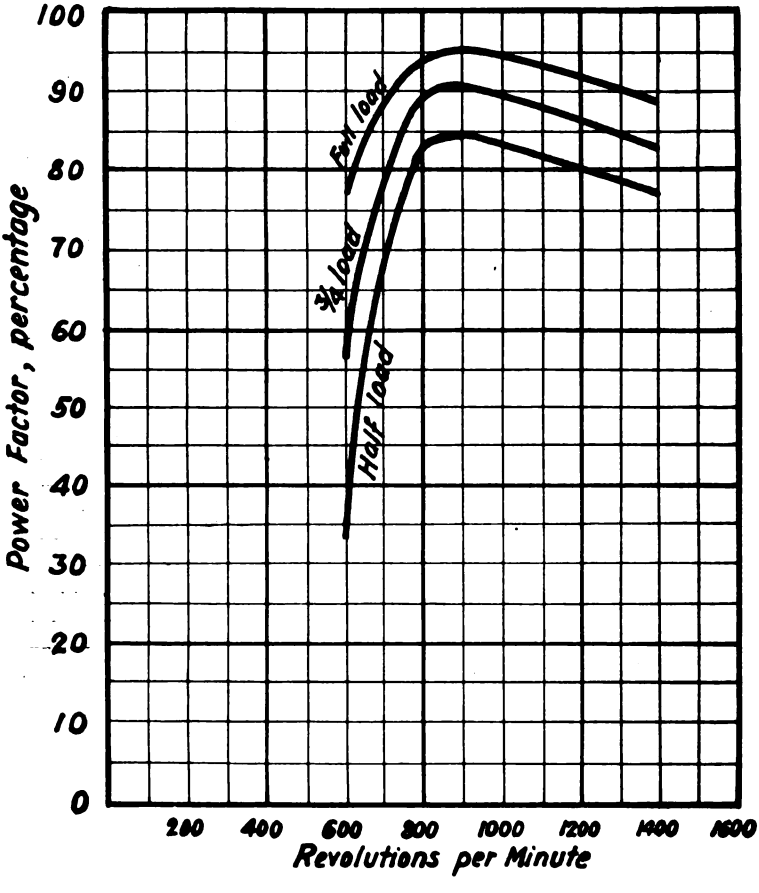


Fig. 28

power-factor below synchronism could undoubtedly be brought up to that at other speeds by suitable compensating arrangements.

The efficiency of the motor has not yet reached a commercial figure, as it did not much exceed 70 per cent. Careful analyses of the losses were made and the low efficiency was found to be largely due to heavy $I^2 R$ losses in the brushes, a rather high brush friction and heavy iron loss. This latter feature, however, is probably peculiar to the motor tested, which had open rotor slots, the winding being secured by numerous bands. Single-phase commutator motors, especially those intended for high frequencies, are never remarkable for their high efficiencies, but a recalculation indicates that the motor tested could be redesigned to have a full-load efficiency not below 78 to 80 per cent at any speed above synchronism, the maximum efficiency probably being about 83 per cent.

These tests, taken at various times and places in the intervals of other work, are sufficient, I believe, to show something of the possibilities of the machine. Some experiments by other workers which still further confirm the foregoing conclusions are, however, described below.

Experiments of Dr. Alfred Fraenckel

The author would like to call attention to the pamphlet of Dr. Alfred Fraenckel entitled "Der einphasige kompensierte Nebenschlussmotor" published in 1908, which contains a theoretical discussion of the compensated shunt induction motor running at synchronism and of the same motor when the speed is adjusted by means of a coil at right angles to the main primary winding. It also contains a number of experimental curves on both of these motors, of which I have taken the liberty of reproducing those relating to the adjustable-speed motor. This was a machine built for 8 horse-power at 200 volts and 50 cycles, and it ran at a synchronous speed of 1500 rev. per min. The armature was approximately 10 x 6¼ inches.

The motor ran sparklessly at all speeds represented by the curves in Fig. 29 to 32, except the very highest (1900 rev. per min. with no load) when there was considerable sparking at full load and overloads.

It will be seen from Figs. 30, 31, and 32 that the power-factor was very near to unity at all speeds, while the full-load efficiency varied between about 70 and 76 per cent.

For a 50-cycle motor this must be considered a very good performance. It will be seen that speed adjustment was obtained between about 1200 rev. per min. and 1900 rev. per min. or from about 20 per cent below synchronism to 25 per cent above a total range of 1.58 to 1.0. The percentage of reduction below synchronism agrees very closely with the writer's motor No. 3, while the latter, by the use of both field and armature control,

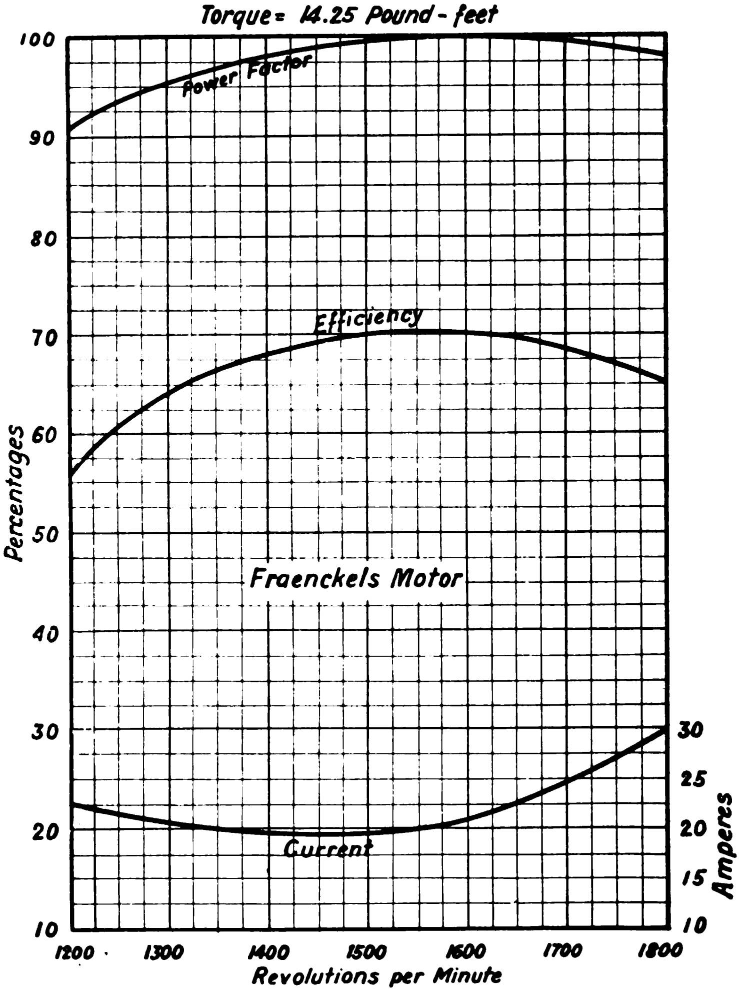


FIG. 29

could be brought up to twice the synchronous speed before the sparking became prohibitive.

It may be confidently stated, therefore, that a speed range of

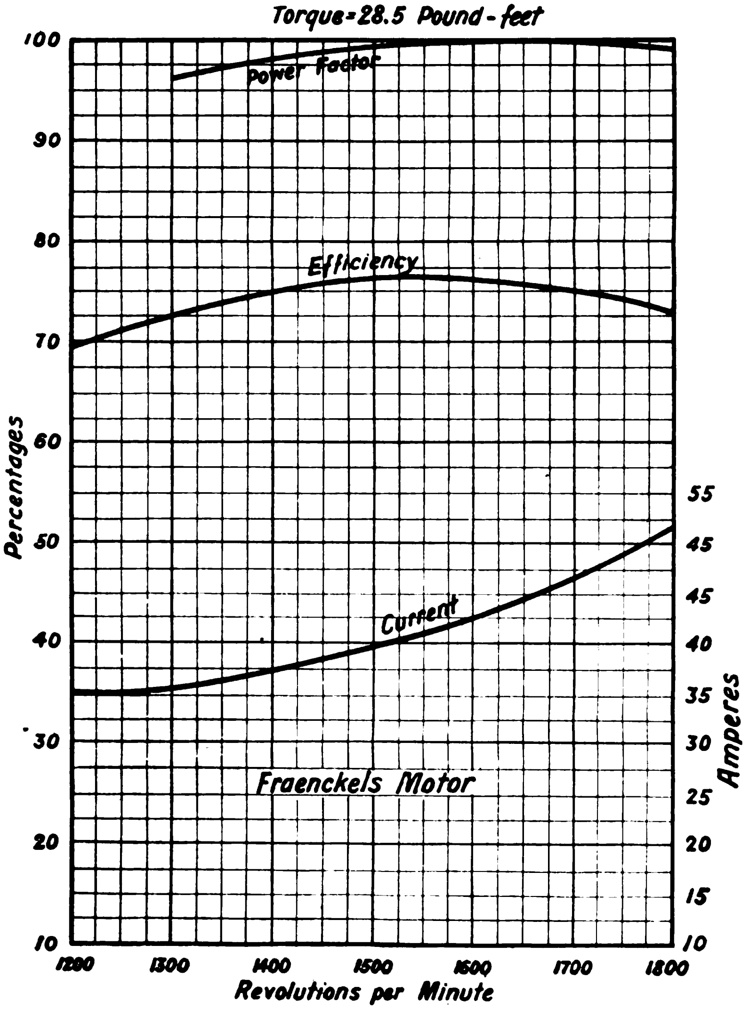


FIG. 30

at least 2½ to 1 is possible on 25 cycles, while a speed range of 3 to 1 could certainly be attained with very little difficulty. If the frequency be increased, raising the speed of the motor in the same proportion and keeping the rotor voltage constant, the sparking voltage will be the same as before. In other words, if the 25-cycle motor be run at 60 cycles, keeping it at the same terminal voltage, the flux will decrease in inverse proportion

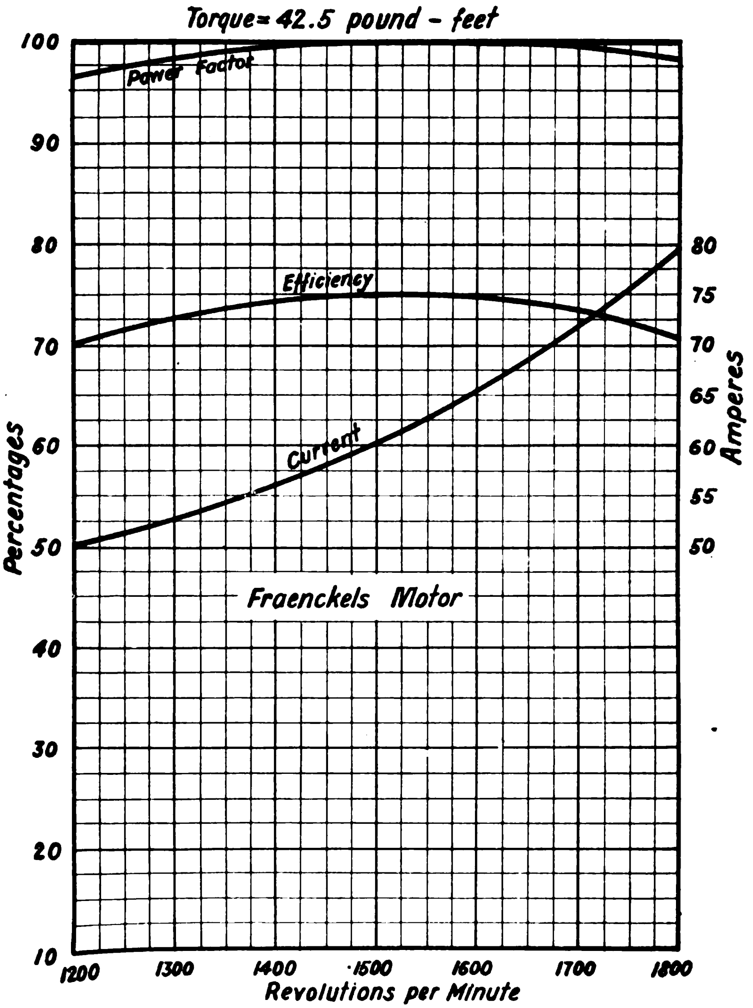


Fig. 31

to the frequency and the speed will rise in direct proportion thereto. The power developed by the motor, of course, remains the same at all frequencies. Assuming that the commutator gives no trouble from vibration, etc., at the higher speed, the commutation will be just the same as before, for the flux goes down in direct proportion to the increase in frequency. Hence the problem of building high-frequency motors reduces to that of building high-speed commutators.

An 8-pole 60-cycle machine could probably be built to run successfully between about 700 and 1600 rev. per min., and probably up to 1900 or 2000 rev. per min. if equipped with a mechanically good commutator. Such a machine would naturally be rather expensive but not more so than the compensated single-phase induction motor running near synchronism, as built by one American and several European firms. The efficiency would also be rather low, having about the same value as in the above-mentioned motor.

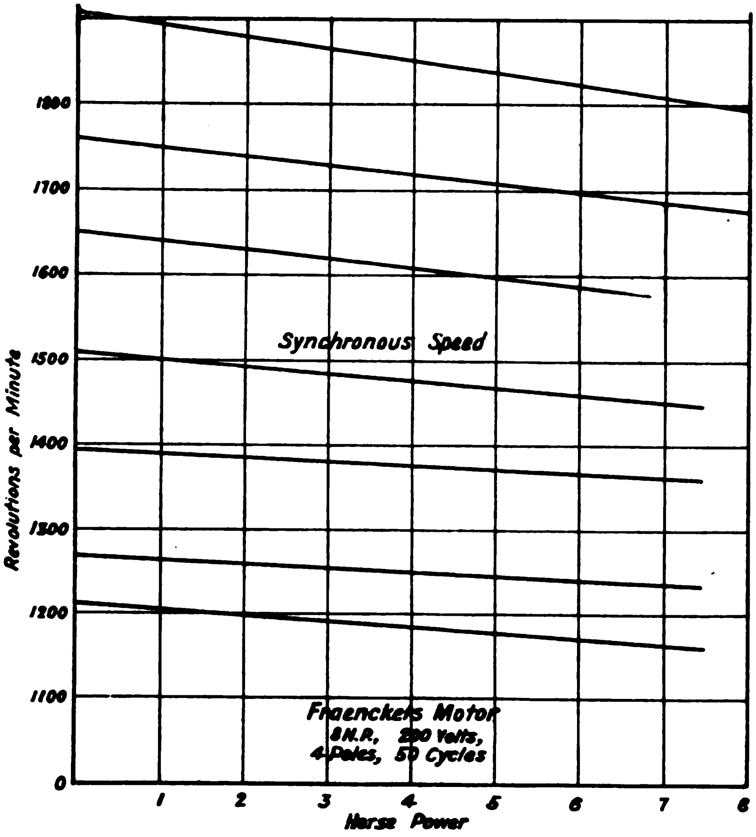


FIG. 32

LIST OF SYMBOLS

E_0' = Compensating electromotive force.

E' = Total electromotive force induced by the field flux in the $X\ X$ circuit (motor of Fig. 4).

E'' = Electromotive force induced by the field flux in that part of the $X\ X$ circuit on the armature (motor of Fig. 4).

E = Transformer electromotive force in a single-phase induction motor; *i.e.*, the electromotive force induced in the secondary at standstill by the primary flux.

E_1 = Electromotive force of rotation induced in the $X\ X$ axis.

E_2 = Counter electromotive force induced by the cross flux on the $Y\ Y$ axis.

E_3 = Resultant of E and E_2.

E_4 = Electromotive force of self induction on the $Y\ Y$ axis.

E_5 = Electromotive force of rotation induced in the $X\ X$ circuit due to the leakage flux on the $Y\ Y$ axis.

E_6 = Counter electromotive force opposing E_4 due to extra current in the $X\ X$ circuit produced by E_5.

E_7 = Counter electromotive force at synchronous speed.

E_8 = Electromotive force introduced into the $Y\ Y$ axis by external means, such as a transformer.

X_1 = External reactance used for varying the speed.

X = Leakage reactance of $Y\ Y$ circuit.

R = Resistance of either $X\ X$ or $Y\ Y$ circuit.

X_0+X = Total reactance of the $X\ X$ circuit.

I_3 = Extra compensating current on the $Y\ Y$ axis.

I_s = Standstill current.

I_0 = Primary magnetizing current.

I_{1s} = Current on the $Y\ Y$ axis at synchronism.

I_1 = Total current in the $Y\ Y$ axis.

I_1' = Load current on the $Y\ Y$ axis.

I_2 = Current on the $X\ X$ axis.

k = Actual speed ÷ synchronous speed.

k_0 = Free running speed ÷ synchronous speed

m = $E_8 \div E_7$.

σ = Dispersion coefficient.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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(*Subject to final revision for the Transactions.*)

SURGES ON A CABLE SYSTEM WITH AN ALUMINUM SURGE PROTECTOR

EXPERIMENTAL INVESTIGATION OF THE SURGES ON AN UNDERGROUND ALTERNATING-CURRENT DISTRIBUTION SYSTEM, AND THE PROTECTION BY ALUMINUM CELLS

BY E. E. F. CREIGHTON AND S. D. SPRONG

The investigations referred to later in this paper were begun by the authors early in the summer of 1908 and covered a period of from eight to ten weeks. The system of the United Electric Light & Power Company, of New York City, seemed particularly desirable for this class of investigation, as it is the largest alternating-current light and power system that is entirely underground and therefore subject to the particular class of phenomena treated by the paper; moreover, it is without the variations that might be encountered in a system having a part of its lines overhead.

The system of the company does not differ substantially from others distributing alternating current underground, but as there are certain minor departures from the usual practice it may be desirable to give here a brief description, so that any small differences can be taken into proper account in a study of the application of the suggested solution to other systems.

The Island of Manhattan, over which the company's system extends, is divided into two approximately equal districts, which are operated independently north and south of Fifty-ninth street. More or less centrally located in either district is a sub-station supplied at 7500 volts, 60 cycles, three phase, from the Waterside Station of the New York Edison Company. In the sub-station this current is stepped down by 2750-kw. air-cooled transformers to 2250 volts, two-phase, and is distributed on the three-wire, two-phase system. All the lighting load and about one-half of the power load are carried on the two outer primary conductors at 3000 volts, thereby nearly doubling the efficiency of the primary distribution and simplifying the question of feeder regulation, which resolves itself into the regulation of the voltage on the outer conductors only.

Each feeder carries an independent district of its own, aggregating about 800 kw. at the peak load. The feeder potential is regulated by an 85-kw., motor-operated, two-phase, air-cooled induction regulator. As only the two outer conductors of the feeder pass through the regulator, as shown in Fig. 1, its effect, as described above, is to increase or decrease the length of each side of the right-angle or quarterphase potentials. This arrangement gives a concentrated inductance in series with the capacity of the feeder, and it is at this point that the problem is met of protection from surge and other abnormal potentials. The potential regulator produces a constant potential of about 250 volts across its secondary, which gives a plus or minus regulation, depending on its phase angle with the main electromotive force. This phase-angle is regulated by the mechanical movement of the motor-operated primary. The constant secondary potential is particularly suited to the application of the aluminum by-pass cells, as will be described later.

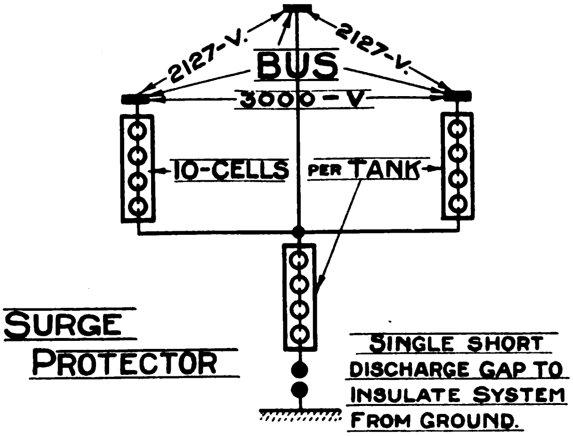

FIG. 1—Connections of the surge protector to the bus bars

The operating experience of the United Electric Light & Power Company, covering a period of some years, has frequently indicated the presence of abnormal potentials which were evidently due to surges. This was shown by punctures on other cables occurring simultaneously or shortly after the grounding of some one feeder. Breakdowns, which usually follow the grounding of a feeder, sometimes happen in one or more of the feeder regulators. This was due, as will be explained, to what may be called the banking up of the potential against the regulator on the feeder side of its reactance.

The total amount of primary cable connected to the bus-bar of each sub-station was about 170 miles during the period of test. This mileage of cable was divided into 14 approximately equal and independent sections, each supplied by a three-conductor feeder on the radial system; that is, the network of primary distributing conductors covering a particular district, is supplied at its approximate load center by a three-conductor feeder direct from the sub-station bus-bar. The capacity current per feeder with its distributors is about 2 amperes per leg, and this capacity, in series with the high reactance of the induction regulators, gives a combination that is dangerous under a wide variety of disturbances.

It may occasion surprise to some that any company would deliberately undertake the hazard of causing surges on its working system, but in considering this point, it should be kept in mind that the United company has the largest alternating-current system that is entirely underground and, therefore has been among the first to observe the results of the phenomena involved and felt compelled in the absence of any other source of reliable information to resort to a practical investigation on their own system. It was decided that, because of the frequency of breakdown and the variety of conditions under which they occurred, the point was being reached that to prevent the conditions becoming still more acute the case needed not so much a desperate remedy as an extreme method of diagnosis. While the method adopted was no doubt radical, it seemed the only possible way to attack the problem with any chance of satisfactory results. The experimental work was undertaken with caution, in that but one step in the dark was taken at a time after which all the data were correlated, including the development of the oscillograph film, so that the drift of the experiment could be checked before the hazard was multiplied further.

It seems hardly necessary to add that these precautions included the application of the aluminum surge protector to the bus-bars at all times, as shown in Fig. 2, and also the use of needle gaps at different points of the system in an endeavor to indicate potentials before they became hazardous. Earlier experiences of the company while operating the uptown and downtown systems in parallel, showed a more extended damage to other feeders when one developed a fault. This bears out the results of the tests showing that extensions of the system lower its natural frequency to such a value as to bring it within the range of the harmonics of the generator. While the expedient of separating the whole distributing network into two districts postponed the possibility of resonant troubles, the system is a growing one, and as further division is not advisable it was necessary to consider the possible extension of some one district to the point where the frequency would come within the range of the usual generator harmonics. The problem lay in either keeping a high natural frequency of the system by subdivision or using some means of absorbing the energy of abnormal potentials.

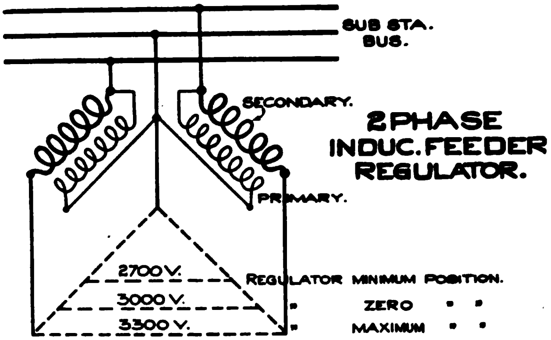

FIG. 2—Connections of the induction regulator

Generally speaking, all alternating-current distributing systems require individual feeder regulation. As any form of regulator must involve reactance, it follows that there will always be the probability of abnormal and often dangerous potentials, as a result of the feeder capacity and regulator reactance. This brings us, then, to the necessity of either taking care of the excess potential on the feeder side of each regulator individually, or by-passing it around the regulator to the station bus-bar, thus making it possible for a single protective equipment to take care of all feeders.

The latter method is preferable, as it reduces to a minimum the investment and bulk of equipment to be provided for in the station. It also provides a way to locate instantly the particular feeder in trouble. As a third advantage, it prevents the piling up of the surge potential on the end-turns of the regulator coils. A further advantage is that by-passing the reactance of the regulator very greatly increases the frequency of the surge and therefore raises it above any possibility of resonance with any of the generator harmonics.

It should be noted in this connection that by-passing a reactance with an aluminum cell almost entirely eliminates such reactance from the circuit. It is for this reason, as described below, that the frequency of a feeder goes much higher than the range of the oscillograph. In other words, by the elimination of the reactance by means of the aluminum by-pass cells, the feeder then oscillates at its natural frequency and the concentrated reactance of the regulator becomes an insignificant factor in its period. It is quite possible that this principle may be employed for other uses than the one covered by this paper.

The first series of tests were carried out with the use of one cable only and its potential regulator. The natural frequency of oscillation, due to a grounded phase through an arc, was of the order of 3000 cycles. Knowing the capacity of this cable, the inductance to correspond to this frequency was calculated and was found to be in the neighborhood of 0.001 henry. This low value of inductance shows that the inductance of the distributing transformers on the circuit with open secondaries is not a factor in this oscillation, since the value of such inductance would be many times greater than the requisite value. The inductance calculated by a short-circuited regulation from tests on the potential regulators, gave the value desired of about 0.001 henry. In other words, the oscillation recorded by the oscillograph shows that the energy of the static charge of the cable passes into electro-magnetic energy in the potential regulator and is re-transformed from one to the other until dissipated.

Later tests were made with an increasing number of feeders from the same bus-bar. It was found that the natural frequency of oscillation, as recorded by the oscillograph, diminished with each additional feeder. With twelve feeders on a circuit, the natural frequency of oscillation had decreased from about

1800 to 680, which is about eleven times the generator frequency. In other words, this system of twelve feeders would resonate with the eleventh harmonic of the generator wave if such an harmonic existed. The potentials across the line coil of the potential regulator showed increasingly higher values as the number of feeders on the system were increased. So far as the oscillograms show directly, these values of surge potential reached the dangerous zone.

By indirect calculation it can be shown that the natural frequency of a cable oscillating by itself may be as high as 25,000 cycles, and such a frequency could not possibly be shown by the oscillograph since the natural frequency of an oscillograph is seldom over 8000 cycles. On careful examination of the oscillogram it is found that the initial deflection when the surge takes place is as instantaneous as the inertia of the moving part of the oscillograph can record. In other words, the discharge from the cable strikes the end-turns of the potential regulator and piles up the potential there. Subsequently the surges " ooze " through the inductance of the regulator and produce thereby a lower frequency at potentials, which, for the simple grounded phase, are less hazardous to the total insulation of the regulator.

What may take place when a grounded phase combines with a short-circuit, as frequently happens, is impossible actually to test, but there is every reason to believe that the potentials will reach a far more dangerous total value across the coils of the potential regulator. The evidence seems to point to the conclusion that the grounded phase does not instantly damage the end-turns where the surge potential piles up, but that the injury is caused by long-sustained surges. Each surge probably causes a small amount of sparking between turns of the coil or between layers, and the dynamic potential difference across the spark is not sufficient to maintain an arc. Each one of these spark discharges probably causes some disintegration of the insulation between turns or layers, and it is only after continued stresses of this kind that the trouble develops gradually into a short-circuited condition of the turns of the potential regulator.

The best means of protecting the potential regulator will be to apply aluminum cells across the regulator coils. This was done in the test, and the oscillogram of the current in the cells circuit showed a maximum rise of over 50 amperes from a normal current of about 0.1 ampere. This test was made with a current transformer in series with the cell, which in itself reduces the natural frequency through the cell circuit. Observations on the cells, without the current transformer in circuit, showed an unusual activity. In fact, never in any test made in the laboratory or in service have the plates shown an equal amount of luminosity on the surface nor have they given out as loud a sound.

OSCILLOGRAPHIC RECORDS.

General comments. While these records are very clear in the film, it is found impracticable to obtain good reproductions unless the curves are intensified. Where so many high-frequency waves appear, the most practicable method of intensification is by means of a pen and ink working under a magnifying glass. In these records this inking has been done with care, although without the engraver's experience. In general the ink lines follow the records. Two things are lost by inking: first, occasionally on the waves are higher harmonics which can be shown only by the fine lines of the record; secondly due to unsteadiness of the hand and width of ink line, a record of an almost instantaneously change, which appears as a thin vertical line, loses this definiteness. These refinements of analysis are in general not important. Some of the lost effects will be referred to in particular in the comments on individual oscillograms.

The oscillograph used in these tests has three vibrators. It will aid in studying these oscillograms to know that two of the vibrators were, with few exceptions, kept in the same part of the circuit. The vibrator giving the middle record was placed between a phase and ground and was maintained in this position in every case where a ground was produced. The last two oscillograms shown, Figs. 23 and 24, are the only ones without a ground. The vibrator giving the lower record was placed in the ground leg of the surge protector, except in Fig. 13. The vibrator giving the upper curve was placed successively in different positions; viz., potential of bus-bars, potential between line and ground, and across the coils of different regulators, both on the grounded phase and the non-grounded phase. In most cases only one factor was changed at a time. These relations are brought out in the *List of comparative oscillograms* given later.

The three wires of Fig. 2 are named as follows: A_2 the middle wire, and B_1 and B_2 the outer wires.

Fig. 3 shows the general connections for test. Under each oscillogram the specific connections are given. Cable No. 109 was grounded in every case except that of the last two records. In these two, Figs. 21 and 22, cable No. 126 was grounded. In all the tests on No. 109, B_2 phase was grounded, but in the tests using cable No. 126, B_1 phase was grounded.

Needle gaps with series fuses and a resistance sufficient to limit the dynamic current to 0.5 ampere, were placed across both the bus-bar and the cable that was grounded. The object of these gaps was to record any possible peaks of potential that were too short in duration to affect the oscillograph. The line potential was 3000 volts and the gap-length equivalent to 6250 volts, but in no case during the test did the gaps spark over. These needle gaps will be referred to again later under the heading *Oscillations under normal operations.*

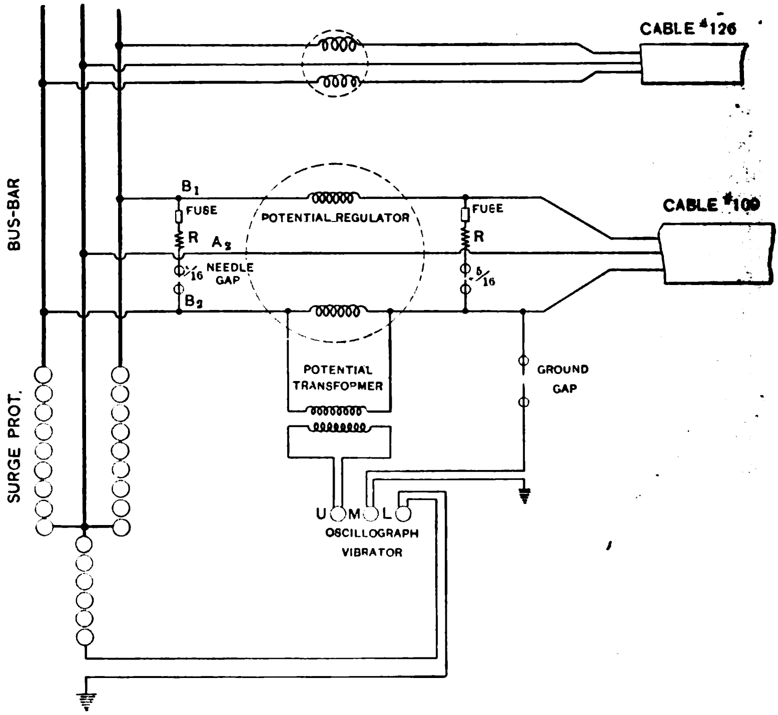

FIG. 3—The general connections of the circuit

In Fig. 4, oscillogram 504, with only cable 109 in circuit,

B_2 leg is grounded through an arc. The middle record shows this current. The rise of current was 68 amperes, although the capacity current is normally only about 2 amperes. This current oscillates during three half-waves of the natural period of the circuit. The gap between line and ground was set at its maximum sparking value and, furthermore, there seemed to have been some rectifying action at the gap which was sufficient to prevent the sparking of the gap when the generator wave reversed. This gives a discharge only at every second peak value.

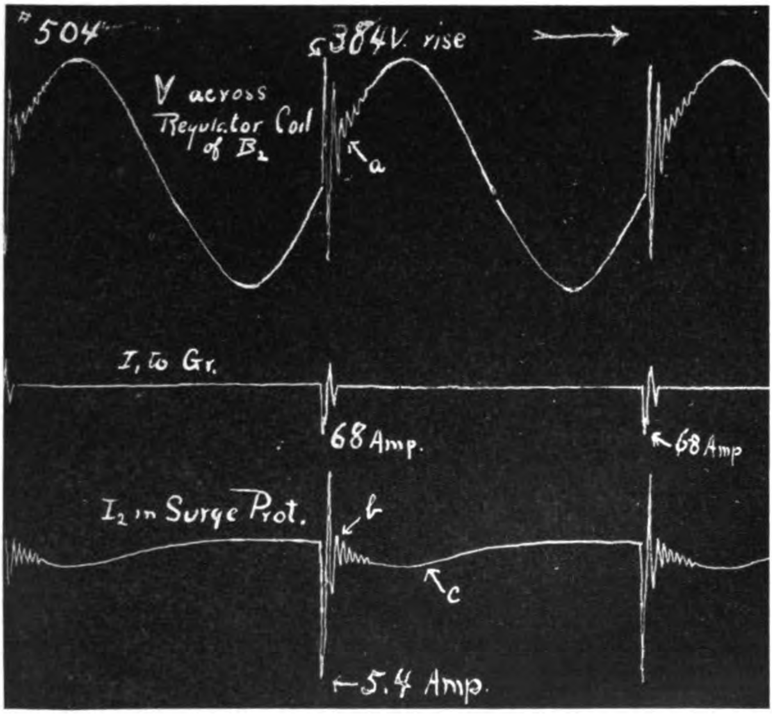

FIG. 4

The upper record is the potential across the B_2 coil of the potential regulator. This is the leg that is grounded. Due to the mechanical position of the regulator, its zero potential corresponds to the maximum across the phase, therefore the discharge occurs near the zero value of the potential of the regulator. There is a sudden rise of 384 volts which oscillates for three half-cycles corresponding to the current to ground. This frequency is approximately 1800 cycles per second. After the arc to ground is extinguished, the system continues to oscillate but at a higher frequency; namely, 3000 cycles per second. This point is shown at *a* and *b*.

The lower record in Fig. 4 is the current through the aluminum surge protector to ground. It shows at *b* two rates of vibration the same as the voltage wave. After the second oscillation ceased, the current still continued to flow to ground through the surge protector as shown at *c*. The arcing ground reduced the B_2 leg to ground potential and thus left the system out of symmetry with the zero potential of the ground. Since the surge protector was the only connection to ground, it carried the quantity of electricity necessary to charge up the ground phase. This change took place through a half-cycle of the generator wave and is shown at *c*. The first half-cycle of the discharge through the surge protector took a longer time than the second half-cycle. This is not true of the oscillations through the regulator coil on the upper record.

One of the characteristics lost in printing is in current discharge through the surge protector. The current starts very abruptly but on reaching 1.35 amperes, stops and recedes a little and then increases more gradually to its peak value of 5.4 amperes. This perhaps is due to the nature of the circuit. At the place where the cable is grounded, on one side is the distributed capacity of the cable and on the other side the inductance of the regulator. The different parts of the system have different rates of discharge due to their natural frequencies, and at any one point these discharges may be moving in opposite directions. Apparently this condition gives the variation in discharge through the surge protector. When more cables are added the results are sufficiently pronounced to be seen. The lower record in Fig. 14 with three cables connected to the bus-bars shows two distinct loops in the rise of the current in the surge protector. In the middle record showing current to ground, there is a hook in the wave of the first half-cycle just after the peak value is reached. When more cables are added this hook disappears.

Fig. 13 shows that the potential across the potential regulator recorded by the oscillograph is not the potential on the end turns, but is less.

In the first set of tests (oscillograms 500 to 517) the arc was produced by opening a knife-switch by hand. In the remaining tests a screw gap was used in an endeavor to produce an arc of constant length. The movement of the screw was controlled by cords attached to an arm and its travel limited by adjustable stops.

In Fig. 5, oscillogram 505, upper record, with one cable in circuit, B_2 leg is again grounded, but the potential is now measured across the B_1 phase of the same regulator. The middle record is the current to ground and the lower record the current in the surge protector. The latter two are identical with the previous oscillogram but the upper record differs in the following particulars:

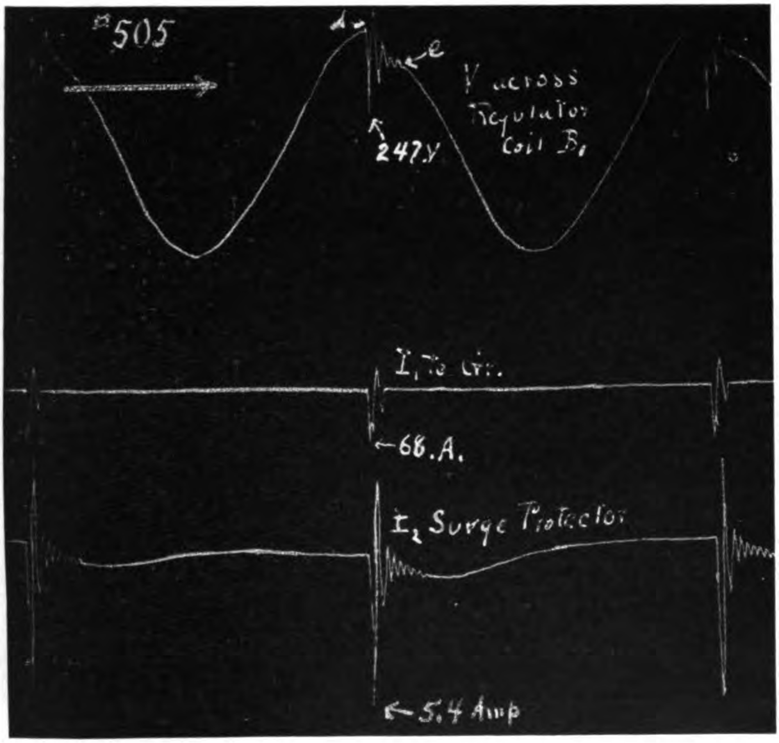

FIG. 5

1. This regulator coil is in the other phase of the two-phase circuit and, therefore, with the same mechanical position of the regulator, the potential must be either 90 degrees ahead or

behind; therefore, the discharge takes place during the peak value of the potential across the regulator.

2. The currents in the B_2 coil (Fig. 4, oscillogram 504) and the B_1 coil (Fig. 5, oscillogram 505) are in the opposite directions. In Fig.4 the surge potential rises with the rising potential across the regulator coil; but in Fig. 5, the reverse is true. Before the ground took place the B_1 phase was approximately 1500 volts effective above the ground, but after the B_2 leg was grounded this potential of B_1 was about 3000 volts above ground. The quantity of electricity to do this was taken through the regulator coils.

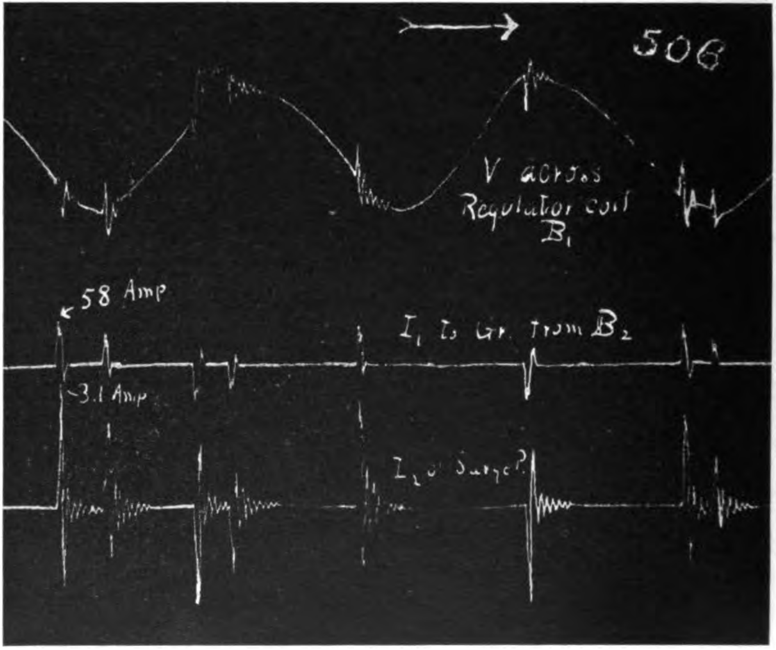

FIG. 6

3. The symmetrical form of the main wave in oscillogram 505 is destroyed by the oscillations. A mean line drawn through the oscillations shows a total drop from the main curve which is not recovered until after the oscillation ceases.

In Fig. 6, oscillogram 506, with one cable in circuit, the same circuit conditions exist as in Fig. 5; viz. the upper record shows the voltage across the B_1 coil of the regulator, the middle record shows the current from B_2 to the ground and the lower record shows the current in the surge protector. The changes are as follows: The scale of the potential wave has been altered to give a smaller record and the gap length between B_2 and the ground is shorter than in the previous test. In consequence of the smaller gap the phase is grounded more frequently and the potential across the gap at the instant of discharge is correspondingly less.

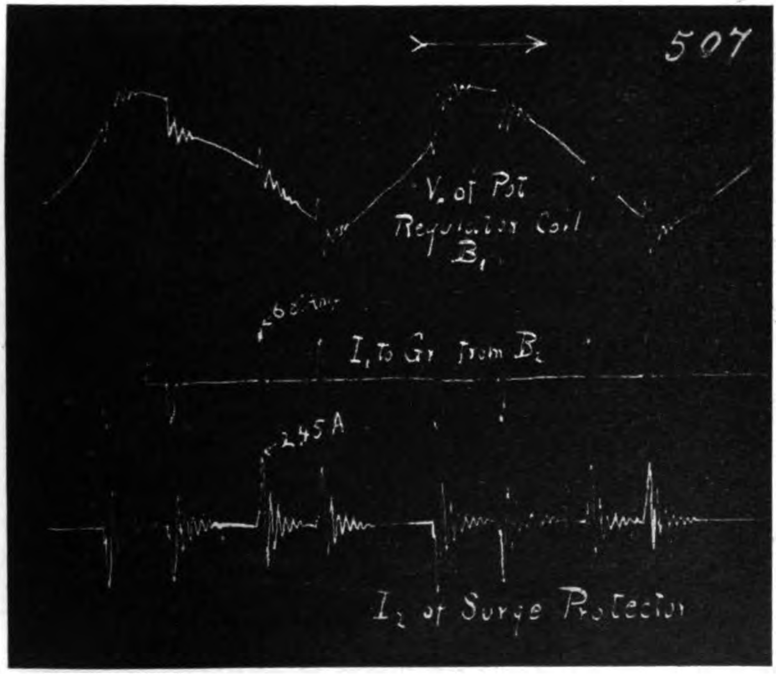

FIG. 7

Fig. 6, oscillogram 506, shows that the distortion of the wave of potential across the B_1 phase of the regulator depends on the condition of the charge of electricity left by the arcing ground. Compare the number of half-waves and the heighth of the final half-wave of each of the oscillations in the middle record with the corresponding disturbance in the potential record.

In Fig. 7, oscillogram 507, with two cables in circuit, the arc length is about the same as in the previous oscillogram the only change being in the increase from one to two cables. This oscillogram does not lend itself readily to the calculations of frequency. The following values are given however: The time of discharge to ground is represented by 1 m.m. equal to 1/2450 second, to which the time of discharge through the surge protector corresponds. Assuming that this wave is not greatly distorted, the frequency should be about 1225 cycles per second. After the ground arc breaks, the remaining oscillations are about twice as rapid; namely, 2450 cycles per second.

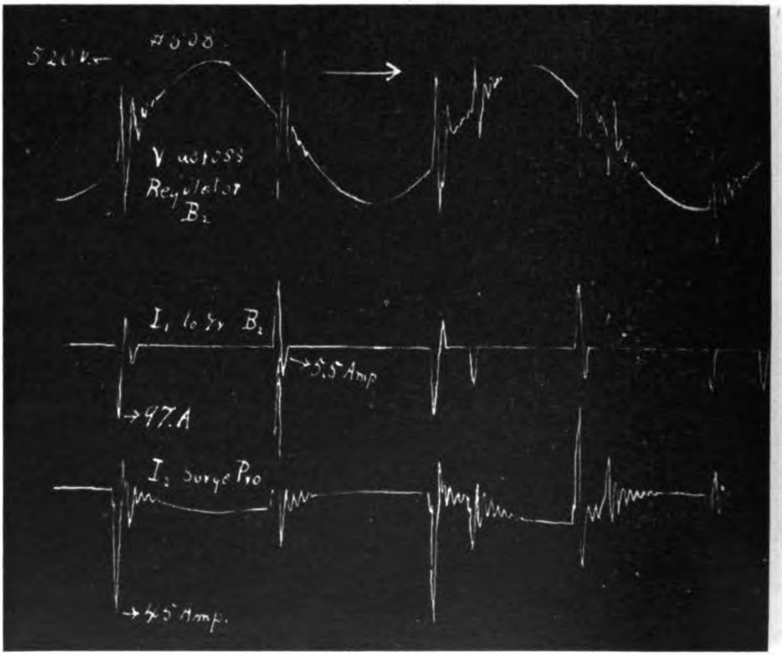

Fig. 8

By the addition of the second cable, little change has been made in the surges. What little change there was lowered the surges. This is shown by the lesser discharge through the surge protector.

In Fig. 8. oscillogram 508, with two cables in circuit, the only change made from the previous test was the transference of the potential vibrator from the B_1 phase to the B_2 phase of the regulator. Inadvertently the arc was a little longer, and in consequence the surge currents were greater and the occurrence less frequent. It is important to note that although the surge current to ground increased from 68 amperes to 97 amperes—only 42 per cent—the surge protector was required to discharge 4.5 amperes, an 82 per cent increase, comparing oscillograms 507 and 508 Figs. 7 and 8.

Except for the difference in arc length and scale for the upper record, Fig. 8, is comparable to Fig. 4, where but one cable was in circuit.

In Fig. 9, oscillogram 509, with two cables in circuit, the circuit connections are the same as in the previous test, but the arc to ground is made of short length. This results in a more frequent discharge to ground; in fact the frequency of discharge is about seventeen times the frequency of the circuit. This is noteworthy and is commented upon later, under the heading of " Artificial Harmonics ". Other than the danger of resonance these surges are less harmful than those due to longer arcs. Fig. 9 is comparable to Fig. 8 for the effect of long and short arcs to ground.

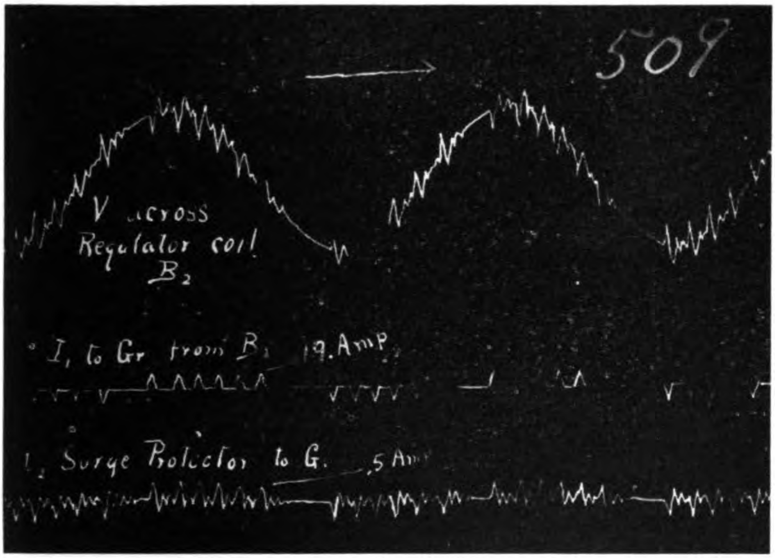

FIG. 9

In Fig. 10, oscillogram 510, with three cables in circuit, the circuit conditions remain the same; namely, voltage across

B_2, coil of the regulator, current to ground, and current through the surge protector. For a comparison of the effect of increasing the number of cables, Figs. 4, 8 and 10 may be used. The general effect is an increase in current to ground and maximum potential across the regulator, but, due apparently to the lower frequency, the surge protector is not called upon for a corresponding increase in discharge.

One cycle of the discharge to ground takes place at the rate of 1120 cycles per second. As closely as can be measured the frequency after the arc to ground ceases is about double this; that is, 2240 cycles per second.

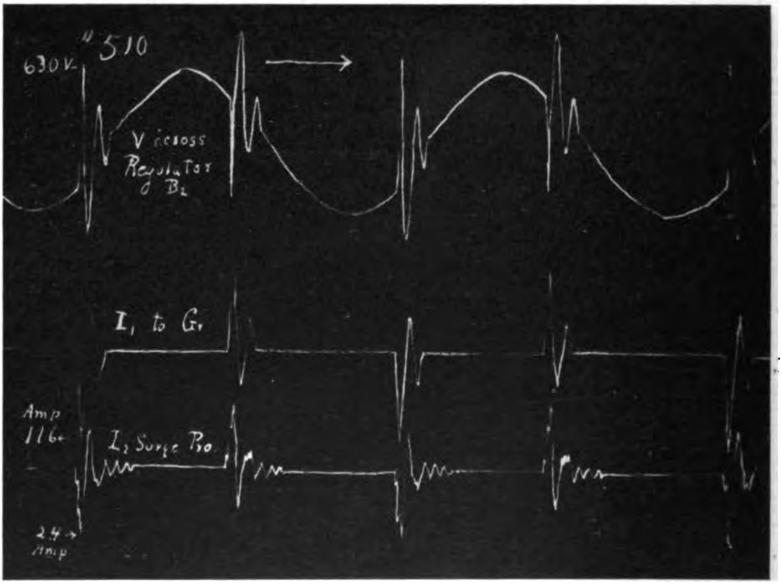

FIG. 10

In Fig. 11, oscillogram 511, with four cables in circuit, the circuit conditions remain the same as in Fig. 10. The voltage rise across the regulator coil and the current to ground have again increased over the condition of three cables. In this case the current in the surge protector has also materially increased. With the increase in current to ground there is a marked tendency for the arc to hold over more than a half cycle. From another standpoint this is a dangerous feature, as it allows of a longer arc—if the arc length were variable—which would produce a heavier surge. The approximately measured frequency is now 920 cycles per second for the oscillation to ground and, as near as can be measured, double this when the ground connection is broken.

In Fig. 12, oscillogram 514, with four cables still in circuit, the potential vibrator has been transferred to the grounded B_2 leg of another (No. 126) regulator. The other conditions remain the same as in 511 (middle record current to ground and lower record current through surge protector.) Oscillograms 514 and 511 give a comparison of the surges in two regulators when the cable of one is grounded. In this case the surges in the grounded potential regulator are more than ten times as great as in the other regulator. Aluminum by-pass cells had been placed across the coils of the grounded regulator No. 109; subsequently the fuse in series with the by-pass cell in the grounded phase was found melted. It is unknown whether this

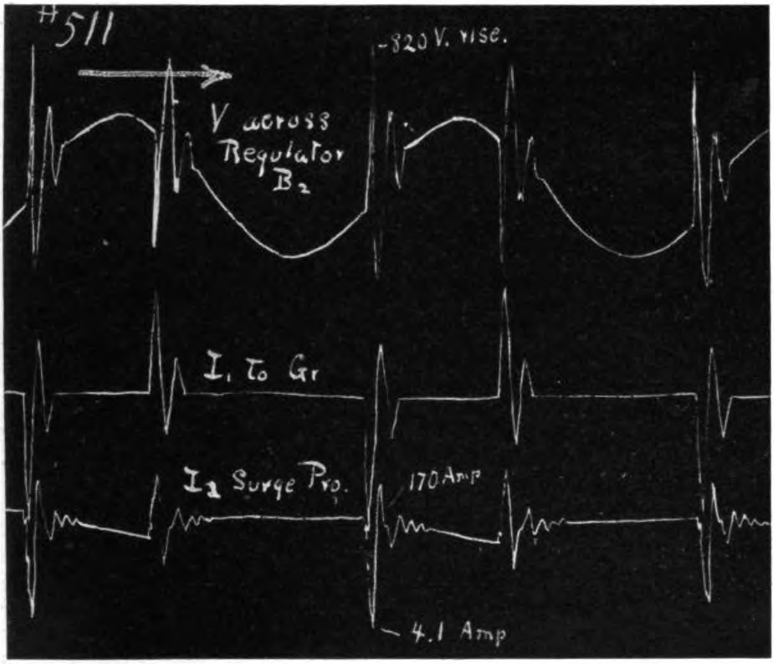

FIG. 11

took place before or after the oscillogram was taken; presumably it fused before the exposure.

The greater values of current in the two lower records of 514 are due probably to a slightly greater length of arc between the line and ground.

In Fig. 13, oscillogram 516, four cables are still in circuit. The potential is again across the grounded phase of the non-grounded regulator. The middle record is the current to ground. The vibrator on the lower record, however, has been changed. An aluminum by-pass cell shunts each side of the regulator (109) that is grounded; in series with the cell in the grounded phase B_2, a current transformer is placed, the secondary of which gives the lower record. Since the natural frequency of the cable with its regulator shunted must be extremely high (over 20,000 cycles per sec.), the oscillograph,

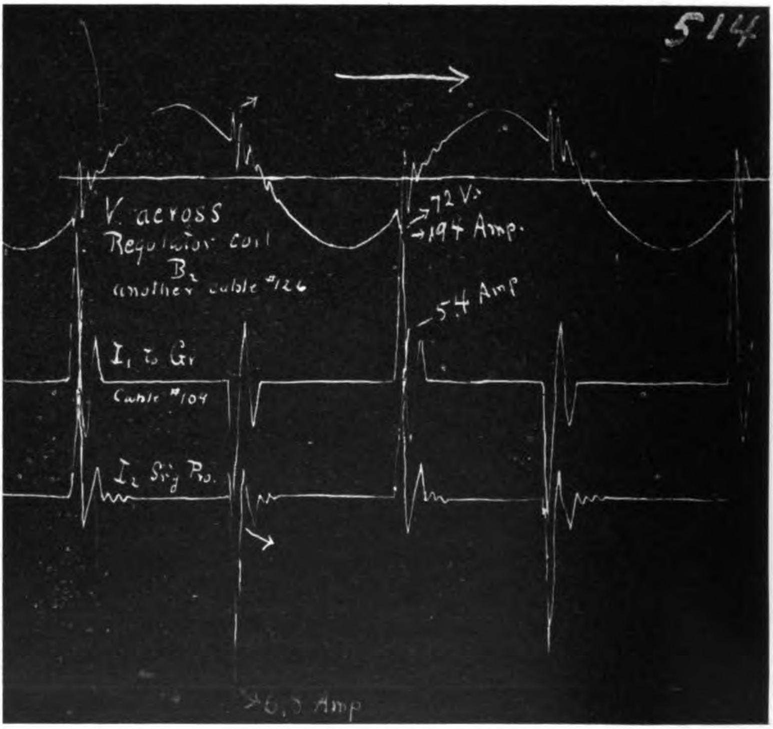

FIG. 12

with its own period of only 5,000 to 8,000 cycles per sec., cannot be expected to follow faithfully the variations in the circuit. The inaccuracies of the vibrator will consist in falling short of the maximum current; but in spite of this it is sufficiently surprising to get a record of 57 amperes in the cell. Another feature is the form of this current wave. The current rises rapidly to a peak value, descends as rapidly, crosses the zero, rises to a considerable value in the opposite direction—all before the current to ground has completed its first half-cycle, and maintains a flat top wave before it again reaches zero.

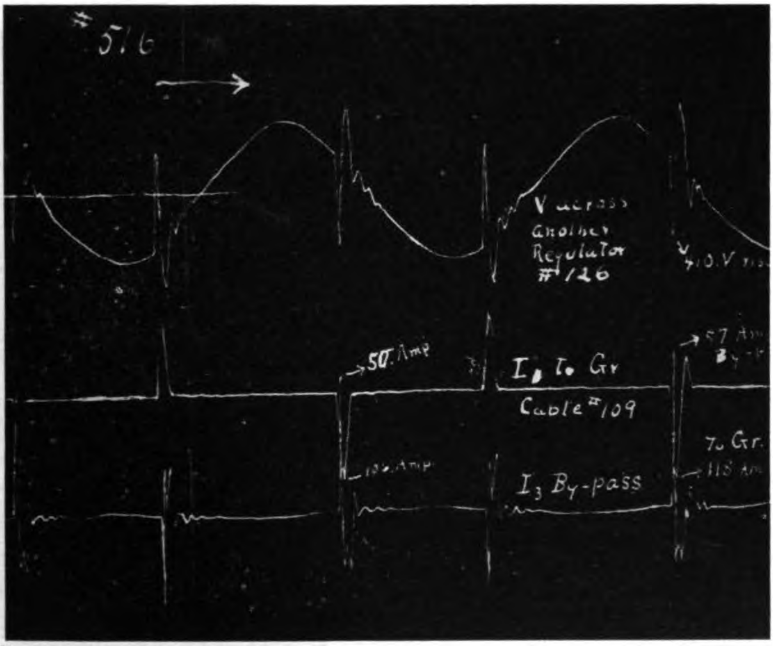

FIG. 13

The potential across the regulator (126) now takes a larger proportion of the total surge.

Another noteworthy condition in this record of current to ground is that the arc is extinguished at the end of the first half-cycle. The only reason apparent for this briefer duration is the presence of the by-pass cells.

In Figs. 14 to 20, seven oscillograms are shown which were taken three days later. The first four, 517, 518, 519, 521, were taken with three cables in circuit with different position of the potential regulator. The last three, 524, 526, 530, of the seven were taken with an increasing number of cables in circuit.

The conditions then for 517 are: three cables in circuit. The upper record is the potential between phase and ground of the grounded phase; in other words, the potential across the arc to ground. The middle record is again the current to ground.

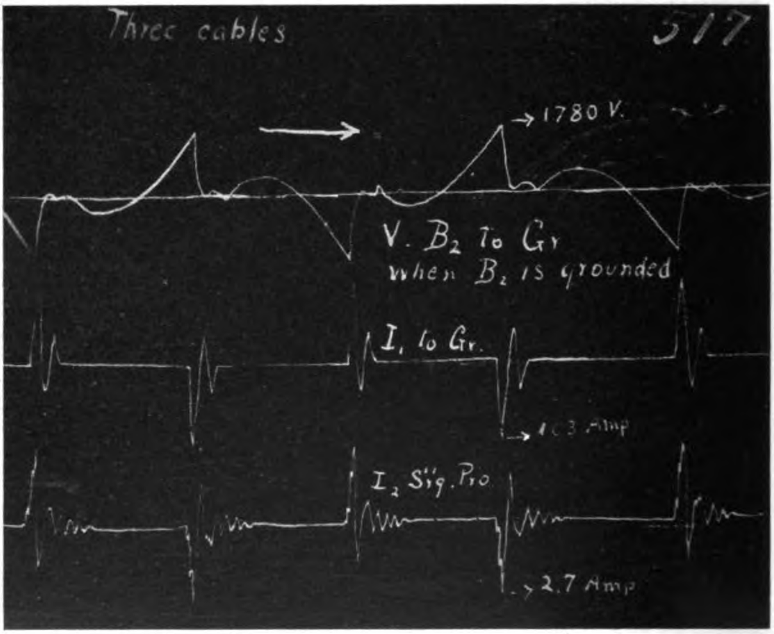

Fig. 14

The vibrator giving the lower record is changed back to the usual position; namely, current in the ground leg of the surge protector.

Commenting on the oscillogram, it may be said that the potential across the gap rises normally to 1780 volts, which is the spark potential; it then drops quickly, but not instantly, to zero, and oscillates slightly across zero while the arc plays. After the arc goes out, the system gradually assumes its normal symmetrical condition of potential, and thus continues until the next arc takes place. (Due to faintness of the lines, one loop of potential was erroneously inked in above the zero. By comparison with the upper record this error will be evident.) The current to ground shows the usual form of discharge, but the current in the surge protector shows *two* distinct halts in rising to its peak value in the first half wave. This same form was shown in oscillogram 510 with three cables in circuit.

In Fig. 15, oscillogram 518 is directly comparable to oscillogram 517 in Fig. 14. The potential vibrator is now between

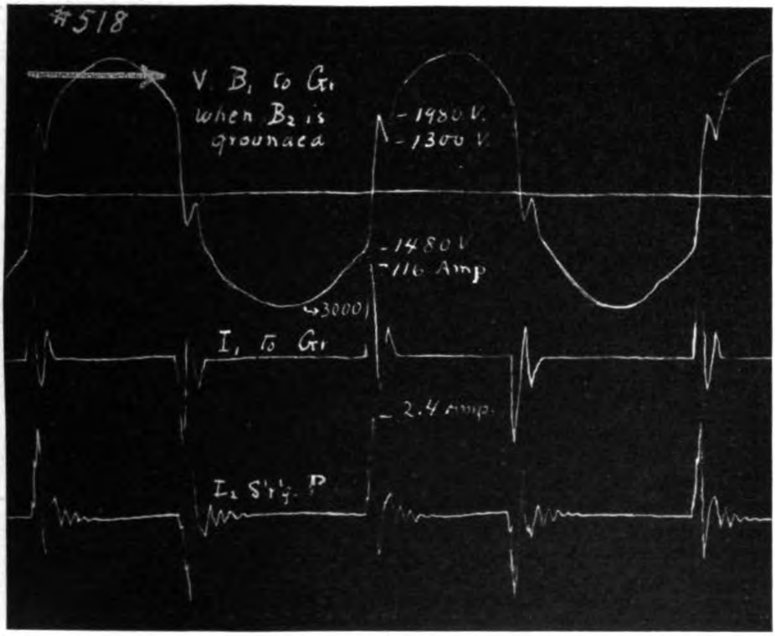

FIG. 15

the other phase B_1 and ground. Since this phase is 90 degrees from the grounded phase B_2, and since it takes a charge from the earth corresponding to the increase of potential above the earth, the wave-form is entirely different from both oscillograms 517 and 510, in Figs. 14 and 10, respectively.

The potential change of the non-grounded phase does not reverse during the first half-cycle of discharge to ground, as it always does *across* the grounded coil of the regulator. The potential of the non-grounded phase gradually changes in one direction so long as the current to ground is in one direction, regardless of whether it is increasing or decreasing, but the potential across the regulator coil has the form of a potential induced by electromagnetic transformation.

The maximum potential in the negative direction is 3000 volts and in the positive direction is 3660. The maximum possible is 3000 × 1.4 = 4200 volts. Any value less than this is due to the fact that after the grounded arc is extinguished the system has not time to regain its symmetrical relation of potential to the ground, which is 4200 volts maximum.

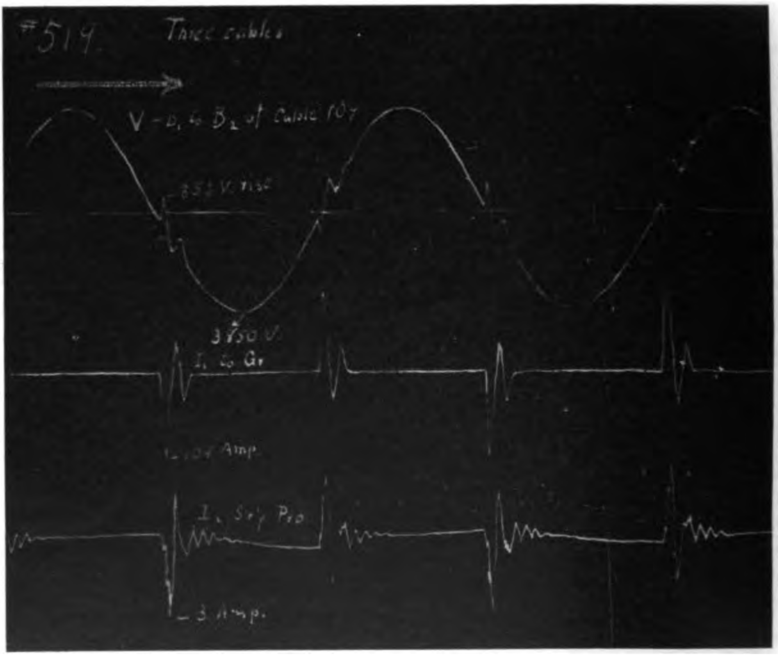

Fig. 16

In Fig. 16, oscillogram 519, the records are directly comparable to those in Figs. 14 and 15. The disturbance in the potential wave between the two phases B_1 and B_2 during the grounding period is noteworthy. Although this disturbance appears relatively unimportant, it is actually a rise of 850 volts corresponding to the voltage added by the surge through the regulator.

In Fig. 17, oscillogram 521, the records are directly comparable to those in Fig. 16. The potential is now taken across B_1 to B_2 on the bus-bars where the surge protector is connected. The disturbance in the potential wave, during the period of grounding, is reduced to about one-third the surge potential across the phases of the cable.

In Fig. 18, oscillogram 524, five cables are in circuit. The records are, respectively: voltage across the regulator coil of the grounded phase B_2; current to ground; and current in the surge protector to ground. The maximum voltage rise is 407 volts; the first peak value of the current to ground is 111 amperes; and the first peak value of the current in the surge protector to ground is 1.7 amperes. This oscillogram is comparable especially to others with a lesser number of cables in circuit.

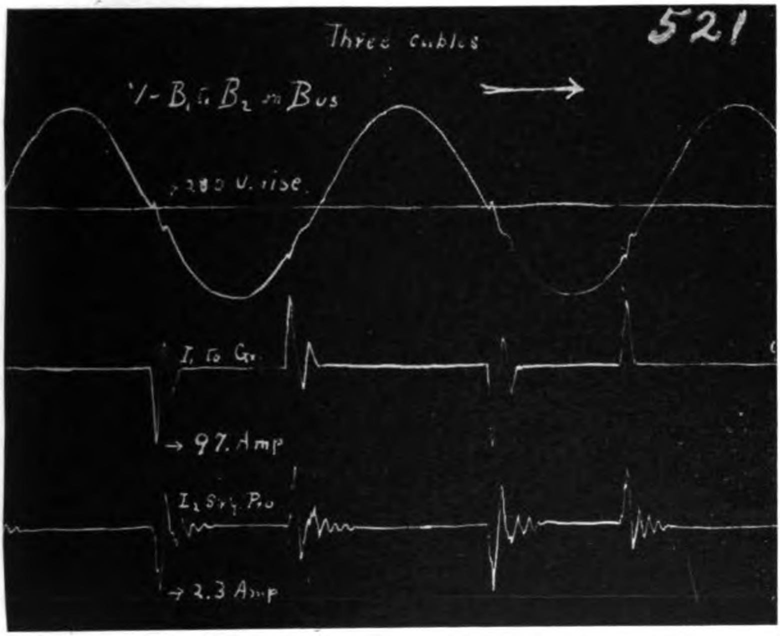

Fig. 17

Making calculations of the natural frequency from the middle record—the current to ground—the following values are obtained.

From	the	first half-cycle	725 cycles per sec.
"	"	second "	1000 " " "
"	"	third and last "	690 " " "
"	"	first complete cycle	875 " " "

The last value is the one used in previous measurements and the one which seems correct to use for comparisons. When not grounded the system oscillates with a frequency about twice as great; viz., 1740 cycles per second.

In Fig. 19, oscillogram 526, six cables are in circuit. The records are, respectively: voltage across the regulator coil of the grounded phase B_2; current to ground; and current in the surge protector to ground. The maximum voltage rise is 615 volts; the corresponding maximum current to ground is 175 amperes; and the corresponding maximum current in the surge protector is 2.4 amperes. This ocillogram is comparable especially to others with a lesser number of cables in circuit. The addition of this cable—No. 120— brings down the measured frequency comparatively little; viz., 875 to 855.

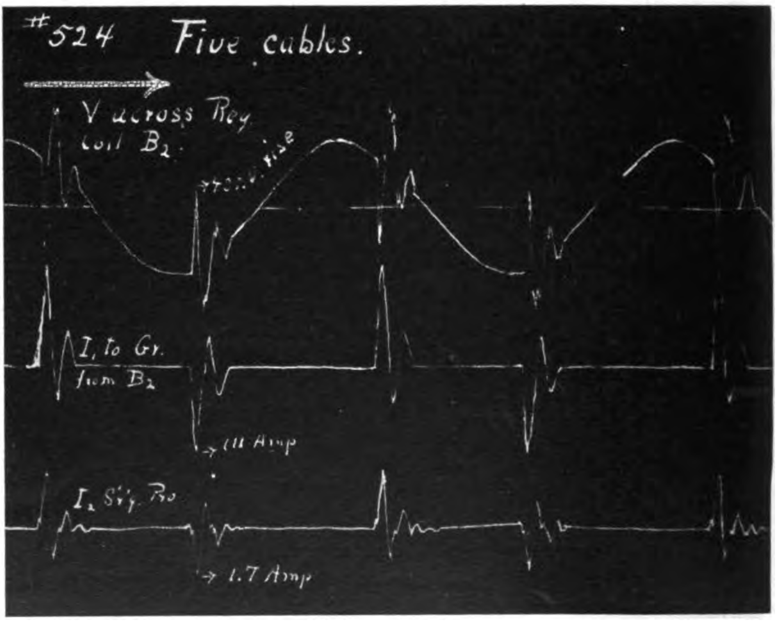

FIG. 18

In Fig. 20, oscillogram 530, seven cables are in circuit. The records are respectively: voltage across the regulator coil of the grounded phase B_2; current to ground; current in the surge protector to ground. The maximum voltage rise is 484 volts; the corresponding maximum current is 135 amperes; and the corresponding current in the surge protector to ground is 1.4 amperes. These maximum values are affected by the arc length, which was not always the same.

Again making detailed calculations of the frequencies represented by the discharge current to ground, the following values are obtained:

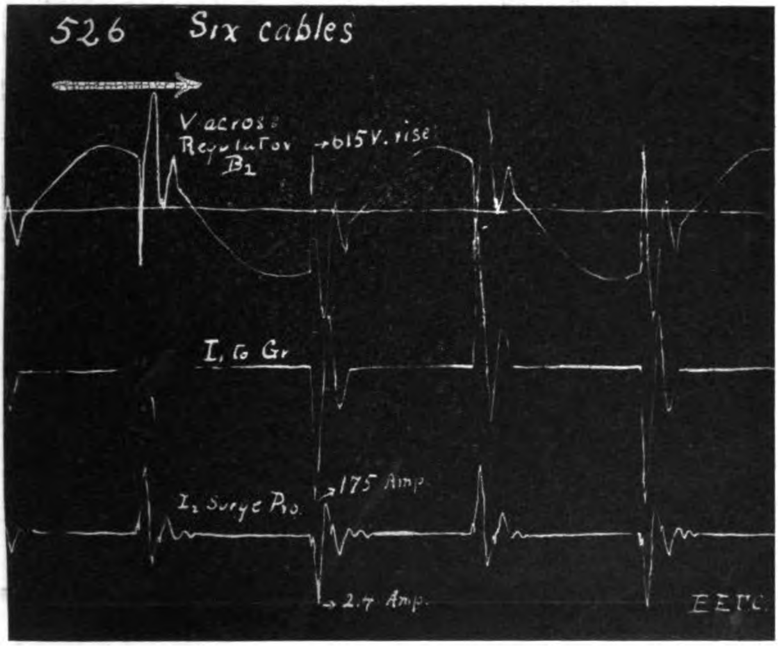

Fig. 19

From the first half-cycle	645	cycles per sec.
" " second "	990	" " "
" " third and last "	590	" " "
" " first complete cycle	844	" " "

The last value corresponds to the one used in the previous measurements.

In Fig. 21, oscillogram 576, four cables are in circuit. The next two oscillograms shown were taken one week later. Instead of cable 109, cable 126 was grounded. The records are, respectively: voltage across the regulator coil of the grounded phase B_1; current to ground; and current in the surge protector to ground. The maximum voltage rise is 520 volts; the corresponding current to ground is 92 amperes; and the corresponding current in the surge protector is 1.4 amperes. The estimated frequency is less than 1290 cycles per second—taken from a cycle of the current in the surge protector.

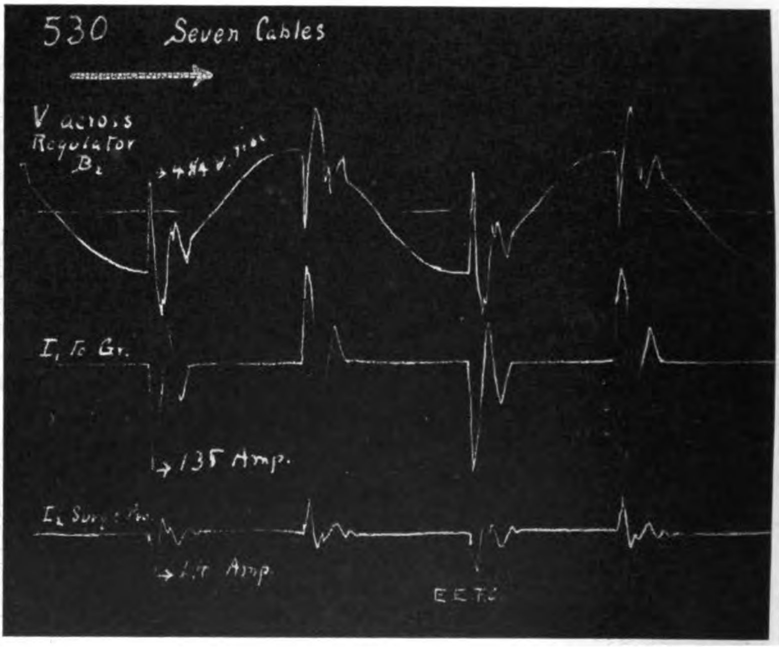

FIG. 20

In Fig. 22, oscillogram 582, twelve cables are in circuit. The records are, respectively, voltage across the regulator coil of the grounded phase B_1 of cable 126; and current to ground. In this oscillogram a new shunt on the vibrator in the surge protector circuit gave a deflection too small to reproduce. The maximum voltage was over 1080 volts across the regulator, which carries normally 250 volts effective. The current to ground was 336 amperes maximum.

Again making detailed calculations of the frequencies represented by the discharge current to ground we have:

From	the	first half-cycle	545	cycles	per	sec.
"	"	second "	870	"	"	"
"	"	third "	500	"	"	"
"	"	first complete cycle	670	"	"	"

The two oscillograms, shown in Figs. 23 and 24, were taken

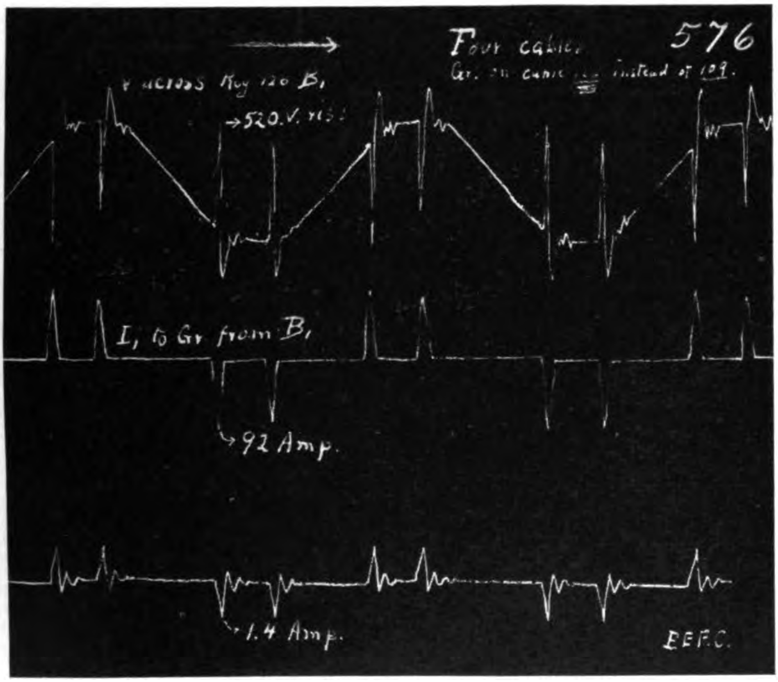

Fig. 21

on a single generator on another system, that of the Brooklyn Edison Company, and are reproduced through their courtesy.

This generator wave shows very strongly the superposition of higher harmonics. Fig. 24 shows the current and potential of the same generator as in Fig. 23 when the generator is attached to the cable system. The capacity so magnifies the harmonics that they predominate over the fundamental. The principal harmonic is the thirteenth, corresponding to N±1 teeth; *i.e.*, twelve teeth per pair of poles.

The oscillogram in Fig. 24 is reproduced to illustrate what resonant conditions might develop. If this generator produced 60 cycles the frequency of the thirteenth harmonic would be 780 cycles per second, and would resonate when placed on a system with conditions equivalent to those of the United Electric Light & Power Co. with eight cables in circuit. This is a graphical illustration of the dangers that may attend the variation or extensions of any electrical transmission system.

Notes.* All long arcs are not necessarily the same length. An endeavor was made to maintain a constant length, but due to inequalities in the crater rims some variations occurred; therefore, there will be corresponding variations in the current and potential values independent of the other controlling factors, such, for example, as the number of cables in circuit.

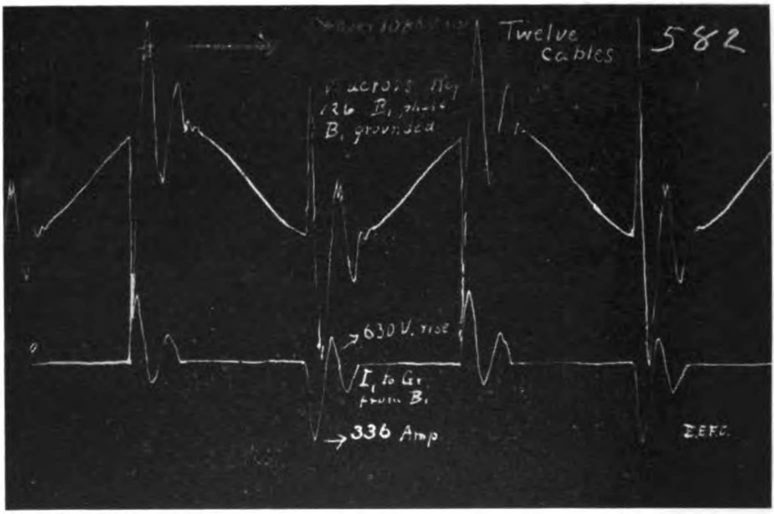

FIG. 22

In brief, the tabulations tend to show the following:

1. A gradual decrease in the natural frequency of the circuit as the number of cables in circuit are increased—see the following tabulation and Fig. 26.

2. An upper limit of three half-cycles of current from the

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* The authors are indebted to Mr. R. H. Marvin for manipulating the oscillograph.

TABULATION OF GENERAL OSCILLOGRAPHIC DATA
THE GROUPINGS BY HORIZONTAL LINES CORRESPOND TO DIFFERENT DATES
(FOR MORE COMPLETE INFORMATION OF THE CIRCUIT CONNECTIONS THE PREVIOUS DETAILED NOTES SHOULD BE CONSULTED)

Fig. No.	Oscillogram No.	No. of feeders	Frequency to ground	Half cycles to ground	Current to ground	Current in surge protector	Maximum voltage rise	Relative arc length	Discharges per cycle	
4	504	1	1800	3	68	5.4	384	Long	1	Voltage across regulator coil (B_2) grounded phase (*A*)
5	505	1	1800	3	68	5.4	247	"	1	" " " " Non-grounded " (*B*)
6	506	1	....	1-2-3	58	3.1	148	Medium	4	" " " " " "
7	507	2	1225	1-2	68	2.45	70	"	4	" " " " " " "
8	508	2	1225	1-2-3	97	4.5	520	"	{4 2	" " " " Grounded " (*A*)
9	509	2	....	1	19	0.5	84	Short	12	" " " " " " "
10	510	3	1120	3	116	2.4	630	Long	2	" " " " " " "
11	511	4	920	3	170	4.1	820	"	2	" " " " " " "
12	514	4	....	3	194	5.4	72	"	2	Another regulator and cells. (*C*)
13	516	4	....	1-2	106	(57.)	410	"	2	(*C*) and *I* by-pass. (*D*)
14	517	3	....	3	103	2.7	Drop	"	2	Voltage between B_2 and ground when B_2 is grounded (*E*)
15	518	3	1020	3	116	2.4	(3465)	"	2	" " B_1 " " " " " " (*F*)
16	519	3	....	3	109	3.0	850	"	2	" " phases (B_1 and B_2) (*G*)
17	521	3	....	3	97	2.3	280	"	2	" " " " " " on bus. (*H*)
18	524	5	875	3	111	1.7	407	"	2	" across regulator coil of grounded phase (B_2) (*A*)
19	526	6	855	3	175	2.4	615	"	2	" " " " " " " " "
20	530	7	844	3	135	1.4	484	"	2	" " " " " " " " "
21	576	4	....	1	92	1.4	520	Medium	4	(*A*) on other cable (*A'*)
22	582	12	670	3	336	....	1100	Long	2	" " " " "
23 24	554 556	Not directly comparable see oscillograms.								

grounded phase to ground, which was limited probably by the length of arc combined with the value of current and the value of natural frequency relative to the generator frequency. There are fewer numbers of half-cycles than three for shorter arcs.

3. A general increase in the current through the arc to ground with an increase in the number of cables.

4. An increase in the current to ground with an increase of spark voltage to ground, which is controlled mostly by the gap length.

5. A variable duty required of the surge protector, which duty apparently depends on the suddenness of the discharge. In general, the duty between line and ground is lessened by addition of cables, but there are some notable exceptions.*

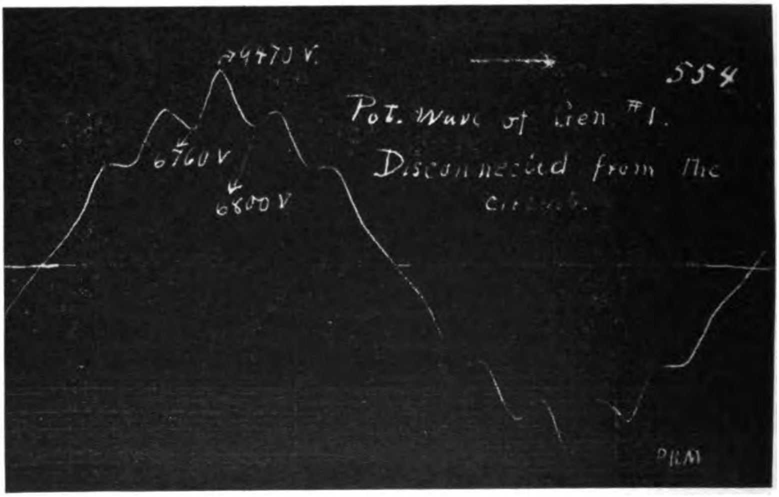

FIG. 23

6. A by-pass cell on a potential regulator is called upon to give a high discharge in order to protect the regulator.

7. The maximum surge voltage across the grounded phase of a regulator coil is directly proportional to the maximum surge current to ground. (Although the ratio on different dates is not identical, each makes a straight line; see Fig. 25).

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* Only surges to ground through the surge protector were measured. The surges from line to line during a disturbance are more severe since they will blow a 10-ampere fuse.

8. The number of half-cycles of potential across a regulator coil is always one more than the number of half-cycles of discharge current through the arc to ground. This is explained by the fundamental law that the induced potential always opposes a change in the current. Therefore, as the surge current increases in the regulator coil, the potential is in the negative direction, but becomes positive as soon as the current begins to diminish.

9. The gap length determines the voltage, and therefore the current, of the static charge to the cable. The shorter the gap length, the greater the number of discharges for each alternation of the generator wave.

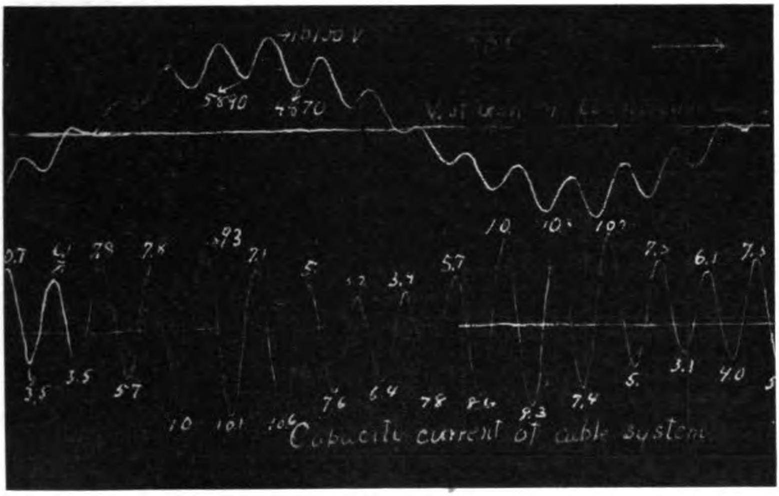

FIG. 24

Relations between the frequency and number of cables. The frequency involves two factors; namely, the capacity and inductance. The capacity varies directly with the cable length, but the inductance depends upon four factors; namely, 1, the length of three-conductor cable; 2, the length of single-conductor cable; 3, the inductance in the regulator; and 4, the inductance in the transformers. In view of the difficulty of separating these factors in the several cables, the assumption is made in the curve shown in Fig. 26, that both capacity and inductance are proportional to the length of cable.

Artificial harmonics. Impulses may be given to the circuit by the variation from a simple sine curve in the main wave—the harmonics—; or, secondly the circuit may get impulses either by electrostatic induction or electro-magnetic induction from an external source. Thirdly, from either of the above sources impulses may be given to the circuit by unbalancing the system relative to the normal neutral. Such an impulse comes from the accidental grounding of one phase through an arc. The arc forms every time the voltage across the gap reaches the spark value and is extinguished as soon as the current dies down. The frequency of the repetition of these impulses will depend greatly upon the length of gap, the conditions of capacity and damping, and the rate of change of potential. As already pointed out in the discussion of Fig. 9 the danger of these short arc frequent impulses or *artificial harmonics* lies in the possibility of their frequency coinciding with the natural frequency of some part of the circuit.

TABLE OF OSCILLOGRAPHIC DATA RELATIVE TO THE NUMBER OF CABLES IN CIRCUIT

No. of oscillo-gram	No. of cables	Fre-quency grounded	Current to ground	Current in surge protected	Maximum voltage rise	Feet cable lengths
504	1	1800	68	5.4	384	38,700
508	2	1225	97	4.5	520	76,800
510	3	1020	116	2.4	630	130,400
511	4	920	170	4.1	820	179,400
524	5	875	111	1.7	407	216,200
526	6	855	175	2.4	615	263,600
530	7	844	135	1.4	484	301,300
576	12	670	336	....	1100	715,400

GUIDE TO FURTHER COMPARISON OF OSCILLOGRAMS.

To compare the effect of lengths of arc to ground use the oscillograms shown in Figs. 5 and 6, with one cable in circuit, or Figs. 8 and 9 with two cables in circuit.

To compare the surges in the two phases of the potential regulator, that is, the grounded and the non-grounded phase, use Figs. 4 and 5, with one cable in circuit; also Figs. 7 and 8, with two cables in circuit.

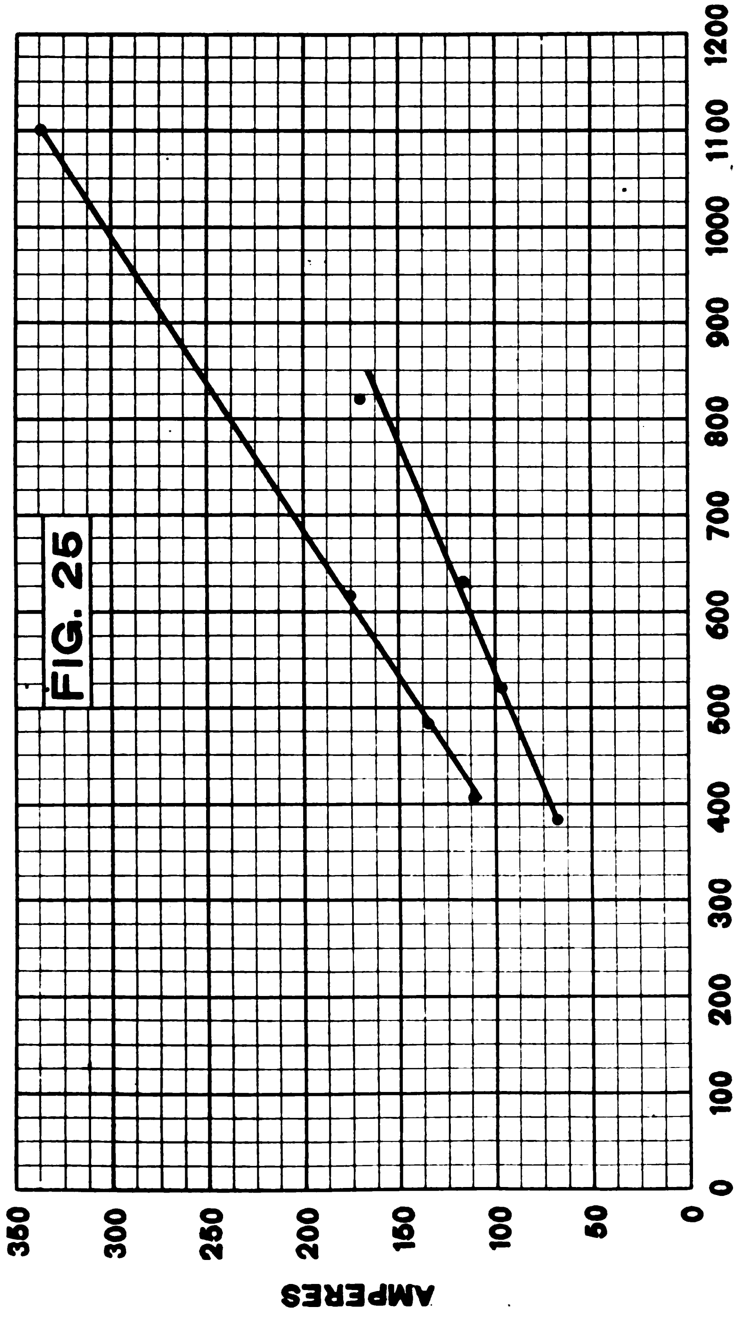

Fig. 25—Relation between the discharge current to ground and the simultaneous potential across a regulator coil

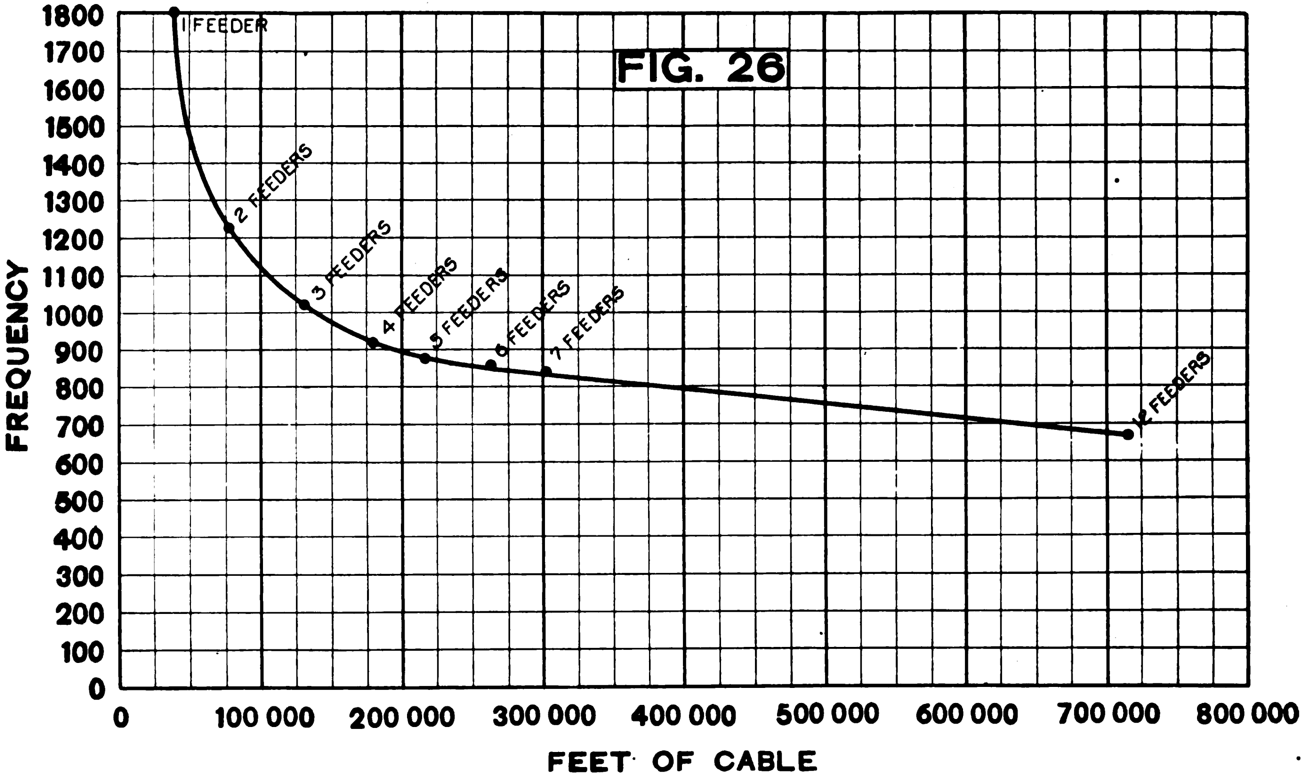

FIG. 26—Relation between the natural frequency and the length of cables in circuit

To compare the voltage between phase and ground of the grounded and non-grounded phases, use Figs. 14 and 15.

To compare the surges between phases on the bus-bar side of the regulator to the corresponding surges on the cable side, use Figs. 16 and 17.

To compare the effect of the number of cables in circuit on the surges in the non-grounded phase of the regulator, use Figs. 6 and 7.

To compare the surges in the same phase in different regulators use Figs. 11 and 12. There is some question of the exact circuit condition in Fig. 12.

To compare the effect of grounding different cables use Figs. 11 and 13, noting that there is a variable between them in the arc lengths.

Surges during normal operation. In all the foregoing the surges were caused by producing an arc between one phase and the ground. During these tests the surge protector was constantly in circuit. Also needle gaps were placed between phases both inside and outside the regulator. The normal voltage between phases is 3000 and the needle gaps were set on 6250 volts. These needle gaps were installed some time before the surge protector was connected and the tests were started. The needle gaps sparked over twice before the tests but not at all during the tests, in spite of the heavy disturbances.

The sources of these disturbances during normal operations is the subject of further investigations. These surges have been observed on other systems. They seldom reach potentials much greater than twice the normal.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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(*Subject to final revision for the Transactions.*)

THE VALUE OF THE CLASSICS IN ENGINEERING EDUCATION

BY CHARLES P. STEINMETZ

Education is not the learning of a trade or profession, but is the development of the intellect and the broadening of the mind, afforded by a general knowledge of all the subjects of interest to the human race, as required to enable a man to intelligently attack and solve problems in which no previous detail experience guides, and to decide the questions arising in his intellectual, social, and industrial life by impartially weighing the different factors and judge their relative importance. These problems, and thus the educational preparation required to cope with them, are practically the same in all walks of life, and the general education of mind and intellect, required by the engineer, the lawyer, the physician, etc., thus is essentially the same. The only legitimate differences in the training for the life's work, required by the different professions, thus are those pertaining to the specific instruction and study of the details of the particular branch of human knowledge, by which the student desires to make his living.

For ages the classics, comprising the study of the Latin and Greek languages and the literature of these languages, has been the foundation of all education; but in the last two generations it has been more and more pushed into the background by the development of empirical science and its application, engineering. It is my opinion that this neglect of the classics is one of the most serious mistakes of modern education, and that the study of the classics is very important and valuable, and more so in the education of the engineer than in most other professions, for the reason that the avocation of an engineer is specially liable to make the man one sided. By dealing exclusively with empirical science and its applications, the engineer is led to forget, or never to realize, that there are other branches of human thought besides empirical science, and equally important as factors of a broad general education and intellectual development. An introduction to these other fields is best and quickest given by the study of the classics, which opens to the student other worlds entirely different from our present, the world of art and literature, of Hellas, and the world of organization and administration—and of citizenship—of Rome, and so broaden his horizon beyond anything which can be accomplished otherwise, and show relative values more in their proper proportion, and not distorted by the trend of thought of his time.

It is true that the classics are not necessary if the aim is to fit the student to ply the trade of engineer, just as that of plumber or boiler maker, and the world, and especially the United States, is full of such men which have learned the trade of engineer. But such learning of the engineering trade can hardly be called receiving an education, and certainly does not fit the man to intelligently perform his duties as citizen of the republic during the stormy times of industrial and social reorganization, which are before us.

There also is a considerable utilitarian value in the classic languages, as the terminology of science is entirely based on Latin forms with Greek and Latin roots, and while the student may memorize the terms of his profession, it is difficult, if not impracticable to memorize all the terms of science with which an educated man must be familiar as those of medicine, botany, mineralogy, etc. This however becomes easy to the student of the classic languages, to whom these terms have a meaning. To eliminate the scientific terms of objects from the language is obviously impossible, as the " common " or " English " names usually are different in different localities, if they exist at all, and thereby indefinite.

The modern languages are not in the same class with the classic languages, as they open to the student no new world, no field of thought appreciably different from our own, and I therefore consider them of practically no educational value. Their utilitarian value to the college student is negligible, as due to the limited time, the absence of practice, and the large number of other more important subjects of study, very few of the college graduates retain even a rudiment of their knowledge of modern languages, and even those few only because they are especially interested in them, have occasion to practice them, and therefore would probably have learned them outside of college. To the engineer particularly, the knowledge of foreign modern languages offers no appreciable help in following the engineering progress of other countries, as practically all that is worth reading is translated into English either in full or in abstract, and engineering publications written in a foreign language are closed to the reader even if he has some knowledge of the language, by his lack of knowledge of the technical terminology of the foreign language.

Since the modern languages have no appreciable educational value, they should be dropped from the engineering curriculum of the college, as their retention violates the principle of the modern college curriculum, to restrict, due to the limited available time, the instruction to those subjects which the student can not acquire outside of the college by self study, or can acquire only under great difficulties. Modern languages do not belong to this class, but are learned just as easily, if not more so, by self study and conversation.

Referring to the classics however; it is true that the methods of their teaching are not the most efficient, and especially the classic literature with which the student is familiarized, is not selected so as to offer the greatest educational value in broadening the student's view, nor so as to attract and retain his interest as much as possible, but rather seems to be the result of survival from previous times.

Thus in Latin the story of war and conquest, of the victory of military organization over mere bravery, in *Caesaris de bello Gallico*, is interesting and instructive, while the Civil war is of less interest. Even to-day *Ciceronis de officiis* is well worth reading, while *Ad Catilinam* is stupefying to the intellect, since any intelligent boy must ask why did the "man afraid of his shadow" not have Catilina arrested and executed for high treason.

In Latin poetry selections from *Ovidii Metamorphoses* are very easy reading, and are a valuable introduction to the classic metre, and interesting in the parallelism of the myths of the classic world with those of other races (the flood etc.), but it is hard to understand the retention of the uninteresting plagiarism of the courtier Virgil in the curriculum, while the most important, in his educational value, and most interesting poet, Horaz, is not read at all in most college curricula. Of all Roman writers, Horaz probably exerts the most broadening influence on the intellect when read under an intelligent instructor; the change from the distortion in which the relative values of persons and things appear to their contemporaries, to the proper proportion in the perspective of history, probably is nowhere so sharply demonstrated as in the relation between the " *libertino patre natus* " and his " protector " and " patron " Maecenas, whose name has escaped oblivion merely by his favorite's favor, while Horaz promises immortality to whatever he addresses, and confers it (*ad fontem Bandusiam*). The reading of Horaz probably is the best remedy for discouragement resulting from lack of appreciation of one's efforts, as the engineer and the inventor very often has reason to feel. Also especially the American, who is generally liable to take himself too seriously, might benefit from the sentiment expressed in *Ad Leuconoen*. In short almost every one of Horaz's poems is interesting and instructive and conveys a moral which we may well listen to.

In Greek prose, *Xenophontis Anabasis* is interesting and instructive in many respects, and may well be followed by the student with maps of the country traversed by the ten thousand. Selections from Lucian possibly are the nearest approach to Horaz in their broadening influence. The Greek drama probably is beyond the scope of reading which can be attempted in a general college course, and also appears to me less important now, where in the modern northern drama we have similar tendencies exhibited. The easy dialect of the κοινη however is within the reach of the student, and at least a part of the new testament may be read in the original and its value can hardly be overestimated in showing the meaningless nature of theological controversies on words of an imperfect translation. The greatest work of the literature of Hellas however is Homer; and here again in many American schools the *Iliad* only is read, possibly from the mistaken notion that it is easier reading, while the far more interesting *Odysee* is slighted, though the latter with its tales of travel and adventure, with giants and monsters, should especially appeal to the American boy, and is of far greater interest and educational value in its minute description of everyday life at the early dawn of human history, in its pictorial expressions of times and occupations, of the time of the day, the coming of night, the dawn, etc. Nowhere possibly is found such a vivid description of omnipotence as in Homer's:

Ἦ καὶ κυανέῃσιν ἐπ' ὀφρύσι νεῦσε Κρονίων·
'Αμβρόσιαι δ'ἄρα χαῖται ἐπερρώσαντο ἄνακτος
Κρατὸς ἀπ' ἀθανάτοιο, μέγαν δ' ἐλέλιξεν Ὄλυμπον.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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THE APPLICATION OF STORAGE BATTERIES TO THE REGULATION OF THE ALTERNATING-CURRENT LOAD AT THE PLANT OF THE INDIANA STEEL COMPANY, GARY, INDIANA

BY J. LESTER WOODBRIDGE

Inasmuch as the paper presented by B. R. Shover before the Institute at the meeting in New York on March 12, 1909, gave a general description of the power plant at Gary, including a brief outline of the storage-battery and regulating apparatus, and the paper presented by the writer at the 25th annual convention of the Institute in 1908, set forth the general theory of the operation of this storage-battery regulating apparatus, it has seemed advisable in this paper, after a brief description of the battery plant and accessories, to dwell more particularly upon a few of the features which have not as yet been fully described, and then to give an account of the actual commercial operation.

The battery proper consists of two series of cells, each series comprising 125 cells. Each cell contains 73 plates measuring 18⅝ in. by 18⅝ in. The capacity of each cell is 4320 amperes at the hour rate, or 8640 amperes at the usual regulating rate. It will be understood of course that this latter rate is more or less arbitrary, and the cells are capable of discharging momentarily at much higher rates under emergency conditions if the service should require. The two series, operating in parallel, are therefore designed to give a momentary output of 17,280 amperes at double the 1-hr. rate at a voltage which may vary from 225 down to 200, depending upon the duration of the discharge, the state of the battery, etc. Discharges as high as 25,000 amperes have already been taken from the battery.

The batteries are installed in a two-story building, one series of cells being located on each floor. Each battery room measures 46 ft. 3.5 in. by 80 ft. 1.5 in. inside. A view of the upper floor is shown in Fig. 1. Ventilation of the battery rooms is provided by forced circulation of air, the air being taken from outside the building and filtered through wet coke to remove all dirt and particles of iron and then forced into the battery rooms under pressure by means of a centrifugal blower.

In order to provide for the automatic transfer of energy in either direction between the battery and the alternating-current circuit, two split-pole converters have been installed, each having a continuous rating of 6800 amperes, direct current, in either direction with a voltage range from 225 to 275 at the direct-current brushes The momentary overload ratings are for 10,000 amperes output as a true converter at 300 volts, or 14,000 amperes input as an inverted converter at 200 volts, the alternating voltage at the collector rings remaining constant throughout these ranges of direct voltage. The converters are six-phase machines arranged for double-delta connection to the secondaries

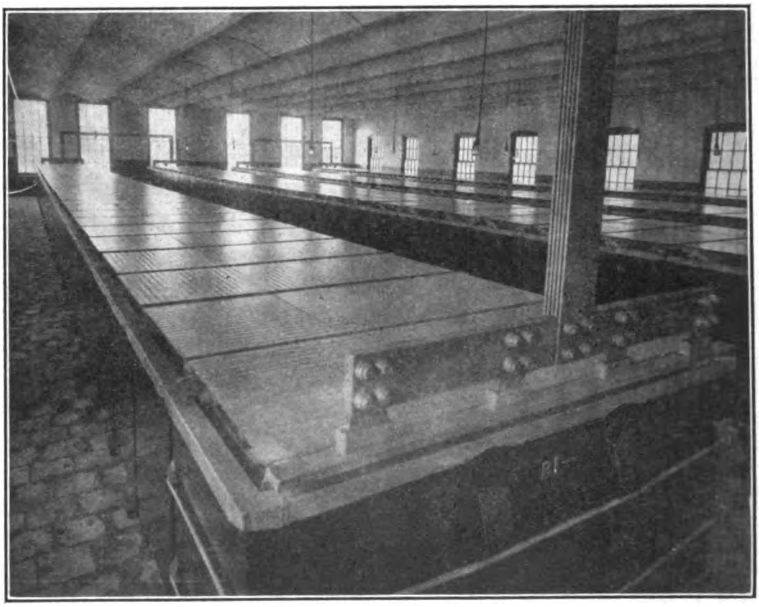

Fig. 1.—Battery room second floor diagonal view, Indiana Steel Co., Gary, Ind.

of the static transformers. Only one of these converters was included in the original installation, the second having been ordered soon after the first was completed and tested. One of these machines is illustrated in Fig. 2.

The direct-current terminals of these converters are connected directly across the battery without the interposition of any booster, and the variation of direct voltage required to cause the battery to charge and discharge is brought about by varying the distribution of field flux over the pole face. The general theory of the operation of this type of machine was discussed quite fully at the last annual convention of this Institute, and it is therefore unnecessary to take it up at length in this paper.

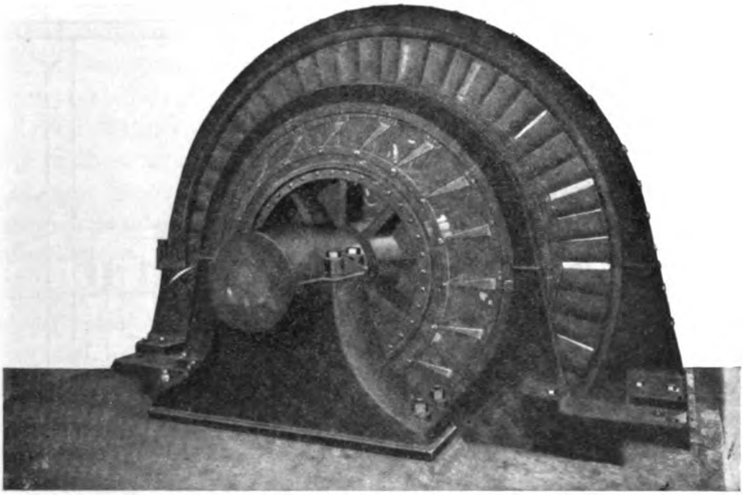

Fig. 2

The converters for the Gary installation were originally designed to operate as three-part-pole machines, each pole being divided into three sections, each section being provided with separate shunt-field windings. In this type of machine, in order to reduce the direct voltage without changing the alternating voltage, the field strength of the outer sections of each pole is reduced while the field strength of the middle section is increased, this change in the distribution of the field flux producing a variation in the voltage ratio of conversion. While the first Gary converter was being built along these lines, the two-part-pole converter was developed. The results of a number of tests on the latter type of machine indicated certain advantages over the three-part-pole type, and finally led to a change in the original plan. It was decided to operate the Gary converter as a two-part-pole machine, two of the pole sections being combined and excited as one, with constant excitation, this constituting the main pole, the third section being used as an auxiliary or regulating section, its excitation being controlled automatically to produce the desired variation of direct voltage. The second machine, being designed to operate in parallel with the first, was made identical with it throughout. The excitation for the two main-pole sections is obtained from the 250-volt exciter bus-bar while the winding on the auxiliary-pole section receives current from a specially designed synchronous exciter.

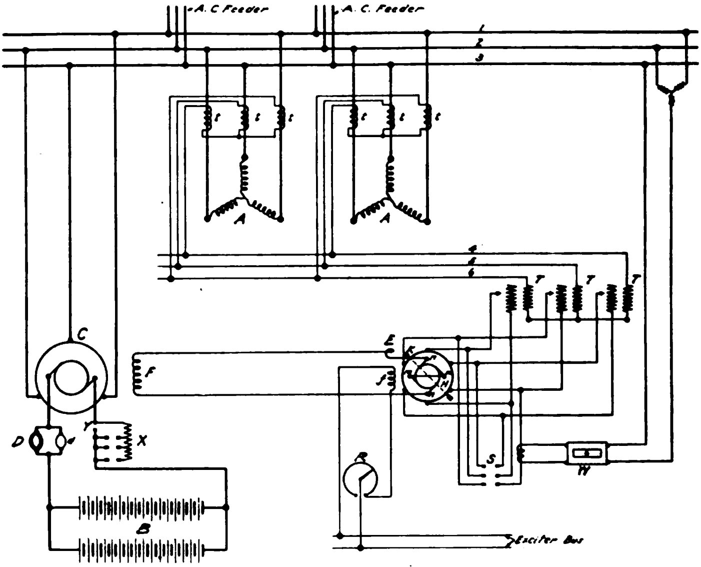

Fig. 3

The theory of this exciter was given in the paper presented by the writer at the 25th annual convention of the Institute in 1908, but it may be well to present a brief review of this theory here. In Fig. 3, which is a simplified diagram of connections of the alternating-current regulating apparatus at Gary, this exciter is shown at *E*. The armature *H* is provided with six collector rings connected to its winding at equidistant points. These collector rings are connected to three current transformers in the alternating-current circuit whose load is to be regulated. The alternating currents thus transmitted through the armature winding will set up a revolving field proportional to these currents. A synchronous motor connected to the alternating-current circuit revolves the armature in a direction opposite to that of the field rotation, thus holding this field stationary in space. The machines are so designed that at unity power-factor this field will take the direction indicated by the arrow *K*. To the armature winding is connected a commutator upon which bear two pairs of brushes. One pair of brushes, *m m* called the auxiliary brushes, is located at points of maximum potential difference due to the field *K*. The other pair of brushes, *n n*, is connected to the regulating field coil *F* of the split-pole converter.

The fields of the exciter are provided with two field windings. One of these is a shunt winding energized from the exciter busbars and controlled by the rheostat *R*. The current in this field winding may be adjusted to neutralize the field *K* set up by the alternating current at some particular load on the alternating-current circuit. Under these conditions there will be no potential across the brushes *m m* and they may be short-circuited, as shown in the diagram. This being done, any change in the alternating-current load above or below the value for which the shunt field of the exciter has been adjusted will produce a difference of potential between the brushes *m m*. A small change in the alternating-current load will be sufficient to cause a very considerable flow of current through the short-circuit connection between these brushes, and this flow of current will set up a second field at right angles to the field *K* and of considerable magnitude. This second field produces a potential across the brushes *n n*, and a corresponding flow of current in the regulating field *F*.

If the alternating-current load has increased, the direction of flow of current in the field coil *F* will be such as to cause the battery to discharge, while if the alternating-current load has decreased, the current in *F* will be in the opposite direction, causing the battery to charge. The second field winding on the exciter is connected in series with the field coil *F* and serves to neutralize the armature reaction due to the current output from the brushes *n n*, and thus makes the machine more sensitive. If the power-factor is not unity the alternating current transmitted from the current transformers through the armature winding may be divided into two components; one of these, the energy component, will produce the field K, while the other, being at right angles to this, will pass directly through the short-circuit between the brushes $m\ m$ and have no appreciable effect on the regulation. It will be seen, therefore, that this machine is responsive to the energy component of the alternating current.

In the Gary installation this exciter is an eight-pole machine,

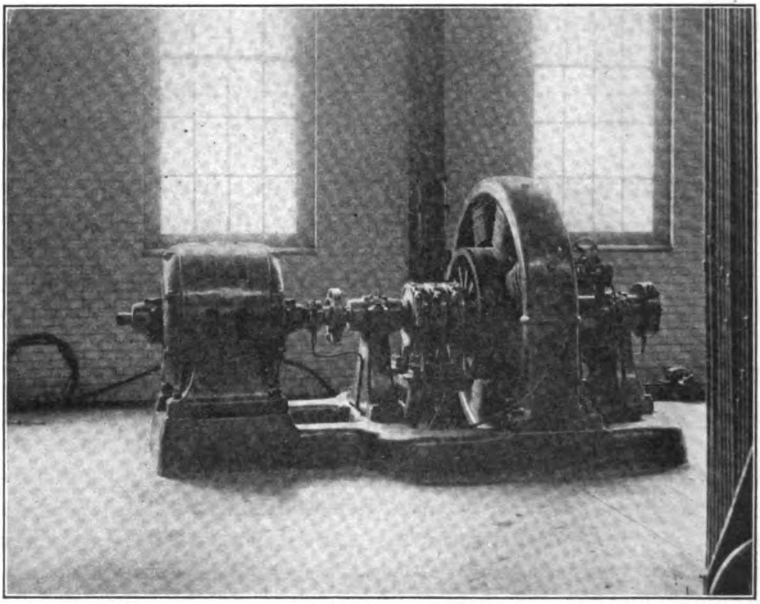

FIG. 4.—Converter auxiliary field exciter, Indiana Steel Co., Gary, Ind.

the armature being provided with a four-pole winding, and is driven by a four-pole synchronous motor. There are eight brushes bearing upon the commutator, four of these being the auxiliary brushes, which are short-circuited, while the other four are connected in pairs and constitute the main terminals of the machine. This exciter set is shown in Fig. 4.

For supplying alternating current to the exciter, a current transformer is connected into each phase of each of the main generators. These current transformers are connected to a set of common totalizing bus-bars, which in turn are connected to the primaries of three totalizing current transformers. The secondary windings of the latter are connected to the collector rings of the exciter. This arrangement was made necessary owing to the fact that there is no point in the main alternating-current bus-bars of the station through which the entire output of the plant passes, the outgoing alternating-current feeders being connected at various intermediate points between the points of connection of the main generators so that there is no point in the bus-bars where a single set of current transformers could be connected for regulating the total load.

Inasmuch as the main bus-bars of the station are installed in duplicate, it was found necessary to duplicate the totalizing bus-bars for the current transformers. The switching arrangements are such that any number of the main generators may be connected to one set of bus-bars, while others may be connected to the other set. The feeders may also be divided between the two sets. The split-pole converter may be connected to either set of bus-bars for regulating. The oil switches which connect the generators and the converters to the bus-bars are installed in duplicate, one set for each set of bus-bars. The oil switches are provided with pallet switches interlocked in such a way that when the converter is connected to one set of main bus-bars the totalizing current transformers are connected to the corresponding totalizing current-transformer bus-bars. When any generator is connected to either set of bus-bars its current transformers are connected to the corresponding totalizing current-transformer bus-bars. The exciter therefore responds to the fluctuations of load on only those generators which are connected to the bus-bars to which the split-pole converter is connected. The totalizing current transformer bus-bars which are not in use for regulating at any time are automatically short-circuited.

One special feature of the regulating apparatus in this installation is the short-circuiting switch across the secondaries of the totalizing current transformers. When this switch is closed all the current transformers are short-circuited through the totalizing current transformers, and at the same time the exciter is short-circuited on the alternating-current side. This reduces the exciter direct voltage to zero and instantly kills the regulation, but owing to the high armature reaction of the exciter only a small flow of current is set up through the short-circuit switch. In fact, at times when the total load on the plant is just equal to the average load which is being maintained on the generators, so that the battery is neither charging nor discharging, the exciter voltage will be zero under normal operating conditions. The short-circuit switch may therefore be closed without producing any effect whatever. Any variation of load from this point will produce a flow of current through the short-circuit switch proportional to the increase or decrease of load, but will not affect the voltage of the exciter. In one of the leads to this short-circuit switch is connected the current coil of a wattmeter, its voltage coil being suitably connected to indicate the energy component of the current passing through the short-circuiting switch. This wattmeter provides a means for adjusting the shunt field of the exciter to any predetermined average load on the generators before opening the short-circuiting switch. In this way the process of putting the regulating apparatus into service is much simplified.

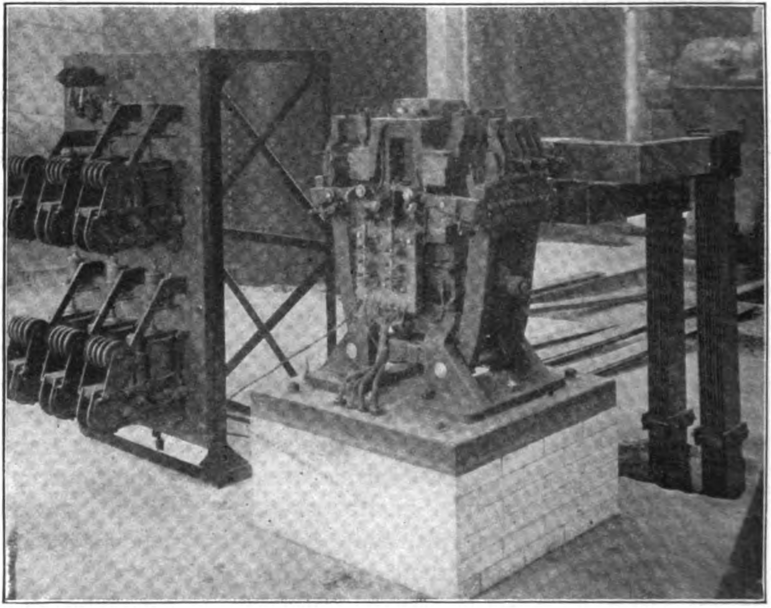

FIG. 5

Fig. 3, as already stated, shows a simplified diagram of connections which will serve to explain more clearly the operation of this regulating apparatus. In order to avoid confusion, most of the switches, circuit-breakers, and duplicate bus-bars have been omitted from this diagram. Two of the main alternators *A A* are shown connected to the main alternating-current bus-bars 1, 2, 3. The static transformers and oil switches which are interposed between the generators and the bus-bars are omitted. Current transformers, *t*, are shown in the generator leads connected to the totalizing bus-bars 4, 5, 6, which in turn lead to the primary windings of the totalizing current transformers *T*. The secondary windings of the latter transformers are connected to the exciter *E*. It will be observed that the ratio of transformation of the totalizing transformers may be varied by cutting in or out coils in their secondary windings.

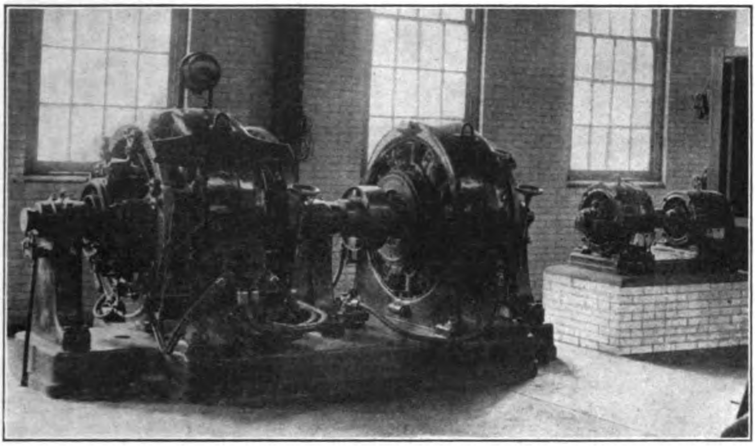

FIG. 6.—Booster and exciter, Indiana Steel Co., Gary, Ind.

This is shown conventionally on the diagram and is accomplished actually by three dial switches connected to a common shaft and operated by a single hand-wheel on the bench-board.

The short-circuiting switch is shown at *S* and the wattmeter connected to one phase of the short-circuit connection is shown at *W*. The rheostat *R* controls the field *f* of the exciter. The main brushes of the exciter are connected to the regulating field *F* of the converter *C*. This converter is shown connected on the alternating-current side to the main alternating-current bus-bars 1, 2, 3 and on the direct-current side to the battery *B*. The alternating-current connections of this converter are shown three-phase conventionally, the static transformers and oil switches being omitted. Actually this is a six-phase machine with double-delta connections to the secondary windings of the static transformers. The multiple-contact resistance for starting the converter from the battery is shown at *X*, the final contact at *Y* being that illustrated in Fig. 5. The two circuit-breakers, *D*, and *d*, are connected in parallel between the battery and the converter, the one of small capacity being used in starting, the other for normal operation.

The method of putting this apparatus into service is comparatively simple. The converter is started by closing its main field circuit and supplying current to its armature from the battery through the automatic starting resistance *X* and the circuit-breaker *d*. The machine is then synchronized with the alternating-current bus-bars and the oil switch is closed. The closing of this switch automatically trips the starting circuit-breaker, *d*, cutting the converter free from the battery. The direct voltage of the converter is then adjusted by its main field rheostat and the running circuit-breaker *D* is closed. The

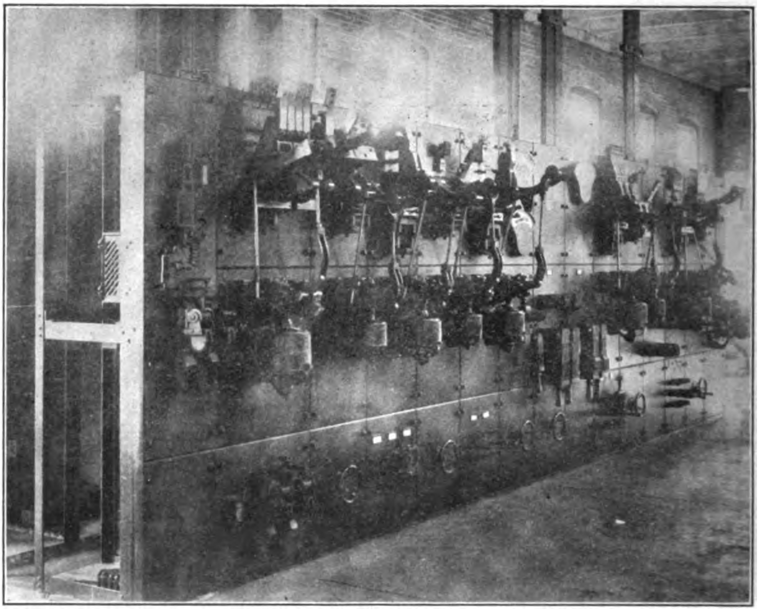

Fig. 7.—Front booster and converter panel (positive side), Indiana Steel Co., Gary, Ind.

battery and converter are then floating on the alternating-current bus-bars. The exciter E is then started up and connected to the field F of the converter, the switch S being closed so that no voltage is developed in the exciter. The rheostat R is now adjusted until the wattmeter W reads zero. If there is a fluctuating load on the alternators the wattmeter needle will be swinging on either side of zero, but the adjustment may be made

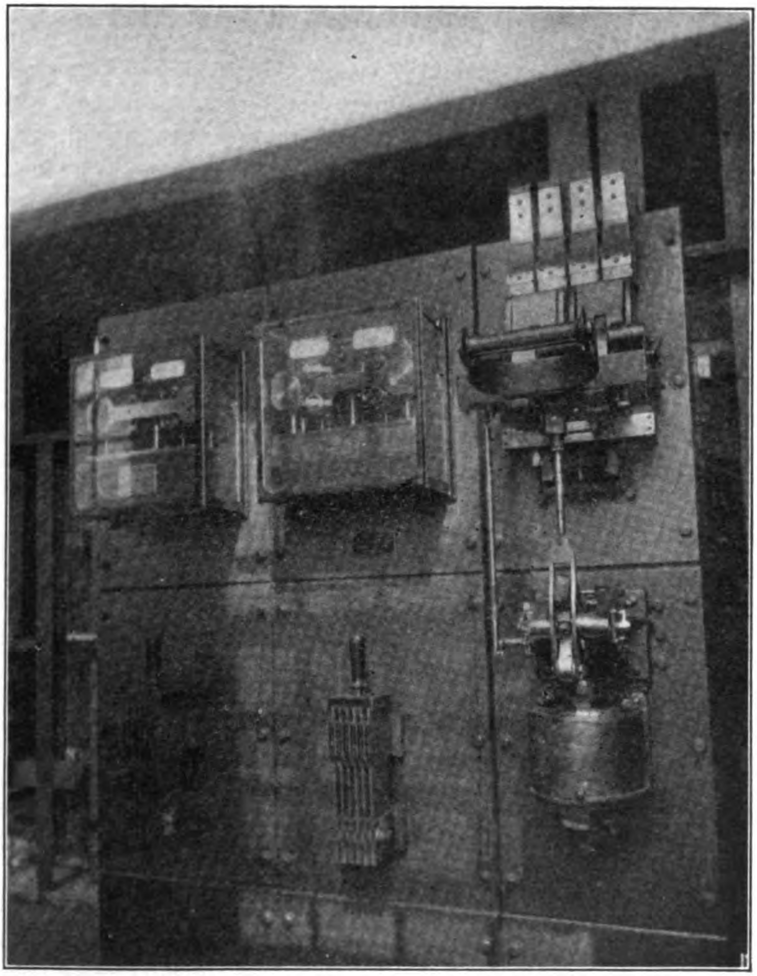

FIG. 8.—Battery switchboard, negative side, Indiana Steel Co., Gary, Ind.

so that when the load on the alternators is at the desired average value, the wattmeter *W* will read zero. When this adjustment is effected the switch *S* may be opened and the regulating apparatus will be in operation.

The battery is also arranged to control fluctuations of load on the direct-current bus-bars, to which it is connected by means of two direct-current boosters which may be operated either singly or in parallel. These boosters are provided with carbon-regulator control in the usual manner, the carbon regulator being actuated by a soft-iron horse-shoe magnet suspended over a portion of the direct-current bus-bar. The operation of these boosters in conjunction with the battery is like any other direct-current regulating plant and need not be further described here. One of the boosters with its exciter is shown in Fig. 6.

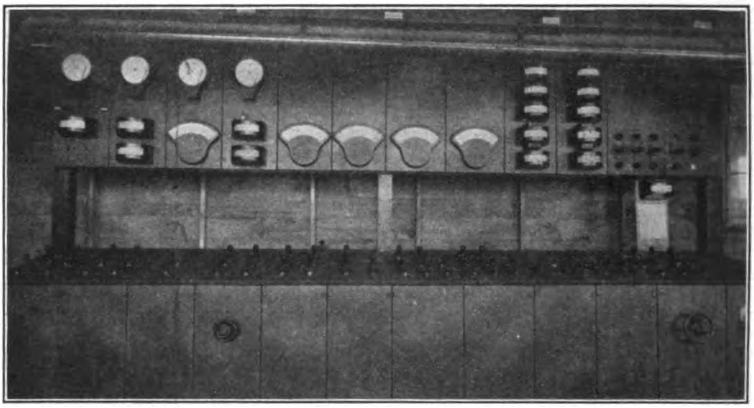

Fig. 9.—Bench board Indiana Steel Co., Gary, Ind.

The main switchboard for this regulating apparatus is located on the ground floor of the power house and is shown in Fig. 7. With the exception of the second panel from the left, which contains switching apparatus for one of the direct-current generators, the apparatus shown on this switchboard is employed for controlling the batteries, split-pole converters, direct-current boosters and exciters. All of the operating switches are of the remote-control type and are operated from the bench-board in the gallery overhead.

A single 25,000-ampere, remote-control circuit-breaker is interposed between the negative bus-bar and the two series of batteries. This circuit-breaker, with the two battery wattmeters, is shown in Fig. 8. The wattmeters are of the double-dial type registering the input and the output of each series of cells separately. The bench-board, from which all of the switches and controlling apparatus are operated, is shown in Fig. 9.

The results of operation of the battery and converter and the regulation obtained on the alternating-current circuit are shown in Fig. 10. In this diagram the heavy line represents the total load on the alternators whose load is being regulated, while the light line is the sum of this generator load and the battery output expressed in kilowatts. These curves were plotted from readings taken at 5-sec. intervals. The total alternator load was read on a wattmeter connected into the circuit of the totalizing current transformers and suitably calibrated, while the readings of battery output were taken from the battery ammeter and voltmeter.

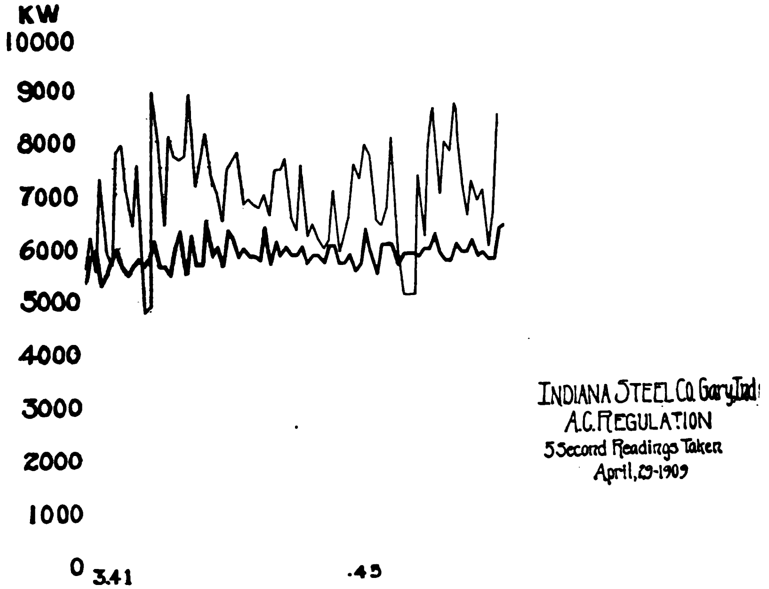

Fig. 10

The effect of the battery regulation on the operation of the entire plant is very marked. In the first place the battery permits the shutting down of one 2000-kw. gas-engine unit, which would be required if the battery were not in service. Even with this additional unit in service, the operation of the plant without the battery involves constant attention by the switchboard attendants and a continual adjustment of generator field rheostats and engine governors. Notwithstanding this constant attention, it is impossible without the battery in service to maintain satisfactory voltage regulation, and the speed of the engines is continually varying over a wide range, whereas with the battery in service the regulation of speed and voltage is all that could be desired.

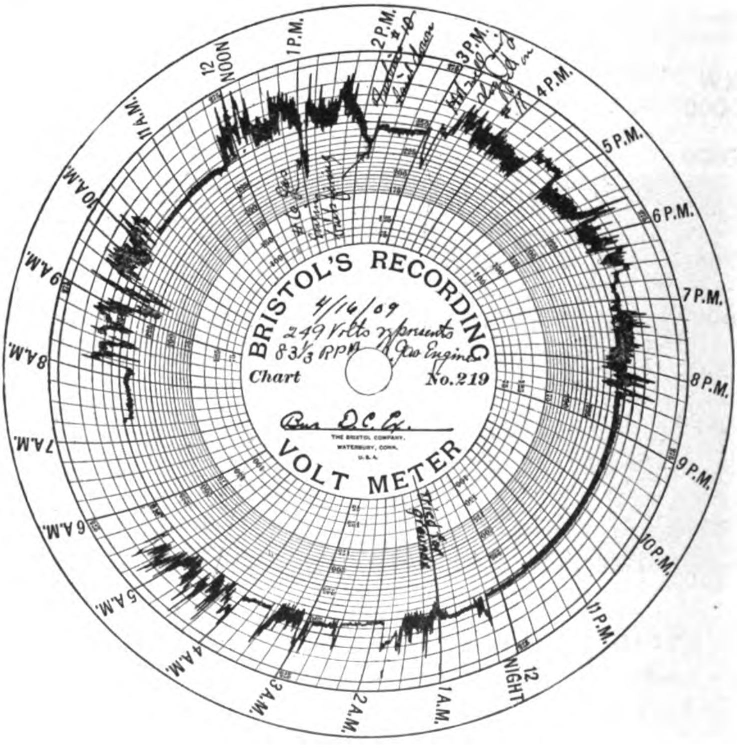

FIG. 11

These effects are clearly shown on the recording voltmeter charts taken from the main exciter bus-bars at the station. Two of these charts are reproduced in Figs. 11 and 12. In explanation of these charts it should be stated that the Gary power house is connected to another gas-engine station in South

Chicago by a three phase tie-line, so that at times the two power houses are operating in parallel. The chart shown in Fig. 11 was taken with the battery out of service, the tie-line to South Chicago being disconnected. The variations of voltage on the exciter bus-bar as shown on this chart are almost directly proportional to variations of speed of the gas engines, since the exciters are driven by synchronous motors. The chart shown in Fig. 12 was taken with the battery in service. From 7 a.m. to 5.35 p.m. the South Chicago tie-line was disconnected, while during the balance of the 24 hr. the Gary plant was operating in parallel with South Chicago. The momentary fluctuation of voltage on the exciter bus-bar occurring at 7 a.m. was due to synchronizing with the South Chicago power house, while a similar fluctuation at 7.30 a.m. was caused by shutting down one gas-engine unit and putting another in service. The severe drop in voltage at 11.15 a.m. was due to the opening of the

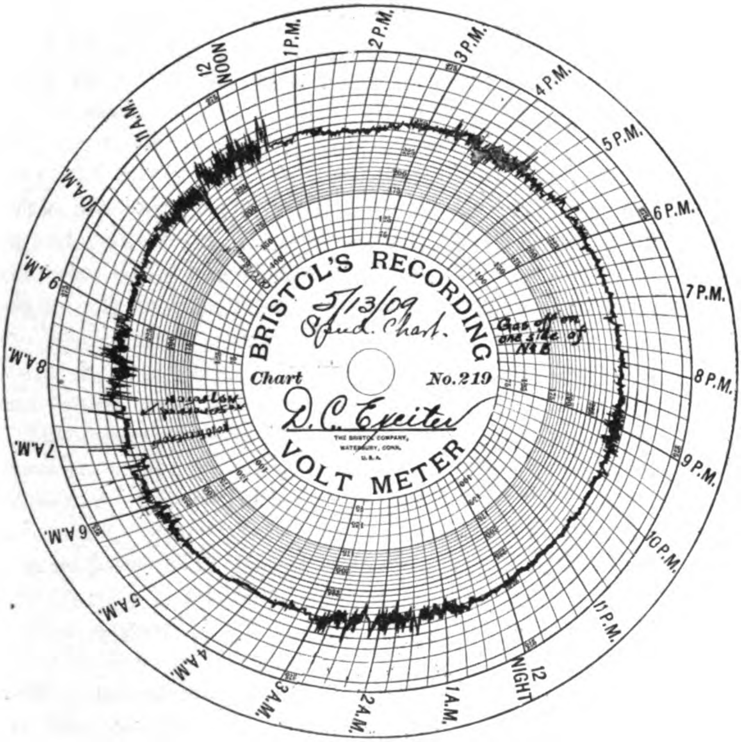

FIG. 12

battery overload circuit-breaker. It should be borne in mind that changes of frequency which are not accompanied by changes of load would not be controlled in any way by the battery regulation and their full effects would appear on these charts

One of the most obvious of the practical commercial results of the battery regulation is the increased speed at which the rolling mill may be operated. When the battery is not in service a very appreciable reduction in the daily output is observed, due to irregularity of speed and voltage.

In addition to this regulating effect, the battery is an ever present source of energy to supply power in case of some emergency such as the sudden shutting down of one of the prime movers or any other partial interruption of the power supply. The vital necessity for continuous power supply to a steel rolling mill is well understood, and the effect of the battery in eliminating costly delays in the operation of the mill would undoubtedly warrant the fixed charges against the battery investment, even if these were not largely offset by the saving in investment for additional generating capacity which the battery replaces.

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SOME CONSIDERATIONS IN DESIGNING HEAVY CAPACITY FUSES

BY LOUIS W. DOWNES

The conditions governing the operation of the open link fuse and the enclosed fuse are radically different. That such a difference exists is due largely to the presence in the latter of a confining case of relatively small dimensions and of a material, the porous filling, which acts in two capacities: first, to disintegrate the vaporized metal; secondly, to condense or cool it and render it non-conducting.

The filling, on account of its porosity, allows the expanding gases to escape in every direction and their continuity is thus broken up. Furthermore, the gases coming in contact with a substance, which is at a temperature many hundreds of degrees lower than that of the gases, are condensed and cooled and thereby lose their conducting power.

This feature is wholly absent in the open link fuse. The gases formed at the rupture simply expand in the atmosphere, and a continuous stratum of conducting vapor is formed between the two terminals of the cut-out in which the fuse is mounted. There is nothing present to disrupt, break up, or condense this vapor other than the air, which can act only in a slight degree and relatively slowly; and in this condition we find the explanation of the tendency shown by the open link fuses, whether multiple or single strip, to arc most violently when subjected to a short-circuit.

On the other hand, the gases so formed in the open link fuse are dissipated with greater or less rapidity into the surrounding atmosphere, and since there is no confining casing, no opportunity exists for the violent explosive action which will occur as a result of the expansion of the metal vapor in the enclosed fuse, if it is not properly designed.

The conditions to be met in the design of an enclosed fuse are therefore materially different from those imposed by the open link fuse. We not only have to suppress the arc but we have to handle the tremendous expansive force of the vaporized metal within a comparatively confined space.

Further, the radiation of the heat from the metal of the link takes place in an entirely different manner. With the open link the heat dissipation is directly from the surface of the metal. In the enclosed fuse, the heat dissipation must take place by conduction through the porous filling to the surface of the tube, so that in enclosing a fusible link and surrounding it with porous material we have modified practically all the conditions of operation.

The most serious difficulty that we have to contend with in the design of the larger capacity fuses is that of explosion, and this difficulty becomes greater as the capacity is increased. The problem is largely one of which we term " volume ratio and distribution;" that is to say, the relation which the volume of the fusible link bears to the volume of the enclosing tube and the distribution of the metal in the filling. Were it possible to carry out the same relationship in the large capacity fuses as that employed in the small capacity fuses, the problem would be too simple and would possess few features of technical interest. It is obviously impossible, however, to maintain this same ratio on account of both cost and dimensions; it is necessary, therefore, to devise other means which, while tending to reduce the volume of fusible metal to the lowest possible point, will so facilitate the ready escape and condensation of the hot metallic gases as to render the operation of the fuse quiet and reliable under all conditions.

Consider more in detail what actually takes place when an enclosed fuse is blown on short-circuit. As the rush of current occurs, the metal is raised through its melting point to its boiling point and the current continues to flow through the fuse for a brief interval on the conducting vapor path of the volatilized metal. It is extremely important that the temperature of these gases should be lowered with the greatest possible rapidity to a point where their conducting power ceases to exist, in order to bring about a reduction in the time of operation of the fuse, which is of tremendous importance in reducing the internal pressures developed and in preventing explosion.

To emphasize this characteristic more forcibly, consider that the maximum running temperature of the porous filling would be slightly less than the melting point of the metal of the fuse link, say approximately 315 degrees cent., were zinc employed and the fuse running at its full load capacity. When a short-circuit occurs, the metal of the link is suddenly raised to a temperature of at least 1000 degrees cent. and as the pressure in the tube becomes greater this temperature is increased. The relatively low temperature of the filling, however, immediately tends to cool these hot gases and convert them from a conducting medium into an actual insulator. Therefore, the sooner we can bring the hot gases into contact with the filling, or conversely, the sooner we can bring all the filling into action as a condenser, the more rapid will be the extinction of the arc within the fuse and the rupture of the circuit.

These considerations show that as little metal as possible must be used in the link and, further, its surface must be so extended as to provide every facility for the hot gases to escape and so distribute the metal within the mass of the filling that each particle of it shall be brought promptly into action.

All these conditions are effectively met by employing what is known as the "multiple link" or one of its modifications. It is quite a simple matter to obtain an increased link area of 100 per cent or more by this method, which will permit of a reduction of at least 18 per cent in the total volume of the metal necessary for a given capacity, according to the design.

Reference to Chart 1, giving an end-section through three types of fusible links, will illustrate how readily this may be accomplished. In Fig. 1 we have an end-section of the widest practical single-strip link which could be used in a given tube. In Fig. 2 is shown how the surface may be readily extended 100 per cent without occupying a greater width, and with a further advantage that the metal is more widely distributed within the filling, rendering this far more effective and rapid in its action. At the same time the metal is brought closer to the radiating surface, which will also affect the total amount of metal necessary for a given capacity of a fuse. In Fig. 3 we have another arrangement of the same link which would also be effective. The mathematical consideration of the effect of a change in position of the conductors within the enclosing casing is interesting.

Applying the equation given in *Watson's Physics* on the transference of heat, and bearing in mind that this applies more strictly to transference between parallel surfaces and where the flow takes place in parallel lines, one can work out an equation which, with a proper value of the factor D, representing the distance through which the heat is transmitted, bears out the author's hypothesis, thus :

Chart No. 1.

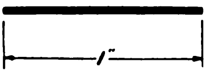


Fig. 1.

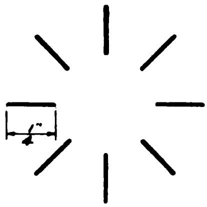


Fig. 2.

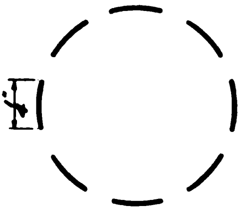


Fig. 3.

Length 3 inches
Area Fig. 1 = 6 sq. in.
Area Fig. 2 = 12 sq. in.
Area Fig. 3 = 12 sq. in.

$$Q = \frac{K\,A\,(T_2 - T_1)\,t}{d} \qquad (1)$$

Where Q = the quantity of heat in calories,

K = a constant for any one substance which is independent of the thickness, area, or the difference in temperature, but changes with the substance used. In this case it refers to the porous filling and the tube,

d = the distance through which the heat is transmitted,

t = the time in seconds in which a given number of heat units would pass from one surface to the other.

T_1 and T_2 are the temperatures respectively of the two surfaces between which occurs the transmission of heat, in this case the temperature of the fuse casing at the surface and the temperature of the fuse link,

A = the area or average cross-section through which the heat passes. Transposing, we get the equation:

$$\frac{Q}{t} = \frac{K A \ (T_2 - T_1)}{d} \tag{2}$$

and representing the calories per second, Q/T by Q', the equation becomes :

$$Q' = \frac{K A \ (T_2 - T_1)}{d}. \tag{3}$$

It is desirable to transform this equation into electrical units.

One calorie per sec. = 4.189×10^7 ergs per sec.

10^7 ergs per sec. = 1 watt.

Therefore, 1 cal. per sec. = 4.189 watts.

From this it follows that

$$Q' = \frac{I^2 R}{4.189} \tag{4}$$

Substituting this equivalent in equation (3)

$$\frac{I^2 R}{4.189} = \frac{K A \ (T_2 - T_1)}{d}, \tag{5}$$

in which I^2R = the total watt loss in the fuse.

Now, transposing and reducing to simpler form

$$I = 2.045 \sqrt{\frac{K}{R} \ \frac{A \ (T_2 - T_1)}{d}} \tag{6}$$

Since K and R are both constant for any given filling and fuse, we may represent $\sqrt{\frac{K}{R}}$ by K' and reduce the formula to a simpler form,

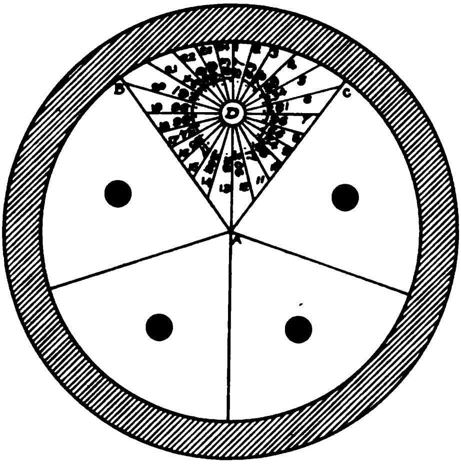
$$I = 2.045 \ K' \sqrt{\frac{A \ (T_2 - T_1)}{d}} \tag{7}$$

As already pointed out, the value d must be determined in each case to meet the condition of divergent heat rays; but once determined, an examination of this equation shows that any variation in this factor, that is to say, any change in the position of the link, affects the current flow. This is further proved by tests of the fuses themselves which will be described later.

It will be apparent that in order to get the most satisfactory operation of an enclosed fuse, and one of the smallest possible dimensions for a given capacity, all the porous filling should be brought into service when the fuse is subjected to an excessive overload or short-circuit.

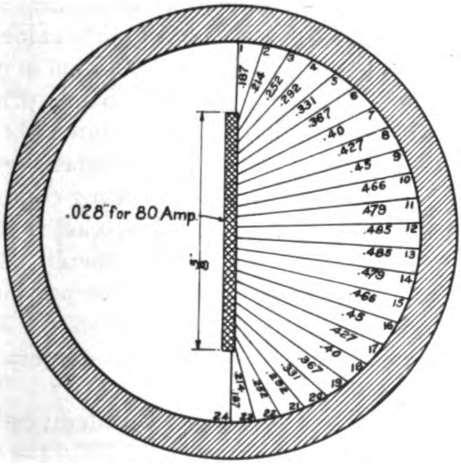
From this it is clear that the shorter the distance the gases have to pass in order to bring into action the maximum amount of filling, the greater will be the rapidity of condensation of the gases and the quicker will the arc be interrupted. To show what an important bearing a proper subdivision and distribution of the metal of the link has in accomplishing this result, consider the fuse sections shown in Chart 2, where in Fig. 1 we have a diagrammatic section through the center of a five-wire multiple fuse drawn three times larger than its actual dimensions. This is divided accurately into five segments, each segment, representing the space which must handle the gases evolved from one element of the link. The circle in the centre of each space represents accurately the proportionate diameter of the wire for a certain capacity of fuse and its relation to the enclosing space. The lines numbered from 1 to 24 represent the mean path or distance that the vapors have to travel in that specific direction in order to bring into action the total amount of filling. It will be understood that in actual practice the number of lines or paths would be materially greater, but for the present discussion any number which would divide up the enclosing space into reasonably even proportions will be sufficient. The length of these lines has been accurately measured and their average length ascertained and found to be, as given in the diagram, 0.192 of an inch in the actual fuse, or in the diagram three times that length. In Chart 2, Fig. 2 we have a similar diagram of a flat-strip link of the same capacity. The space through which the gases will have to pass has been divided into an equal number with those of the multiple link and their average length determined. In this case the average length is found to be 0.363 of an inch, or with the flat

Chart No. 2.



Average length of vapor path=.192"

Fig. 1.



Average length of vapor path=.363"

Fig. 2.

link the gases have to pass through an average distance 89 per cent greater than in the five-wire multiple link. In other words, the time which must elapse before all the filling can be brought into action to condense the vapor is nearly double, with the result that a larger amount of energy is absorbed by the fuse, the current flows longer through it and the breaking or rupturing of the current becomes far more difficult. This furnishes another reason why an explosion will take place with a single-strip link and will not take place under similar conditions with a multiple link. With the single link in a given period of time a much smaller quantity of filling can be reached by the gases, with the result that the condenser or cooling action is not sufficiently rapid to prevent the pressure reaching a disruptive point, and the fuse explodes. With the multiple link, according to the above comparison, practically twice the mass of filling is brought into action in the same period, and the cooling rate is so rapid that explosive pressures are not developed. That this theory is correct is shown both by the oscillograph records referred to later, and by actual test of the fuses themselves.

To ascertain definitely the actual reduction in metal volume for any given capacity of fuse, obtained by proper subdivision of the link, an extended series of calibration tests were made on a set of fuses under identically the same conditions. These fuses were all made up in tubes of the same size and fitted with the same size terminals, the lengths of the links being the same. Reference to Chart 3 gives tabulated data for the reduction in metal secured with both the round wire link and the flat strip link, showing clearly the effective reduction in metal volume obtained in this way. Reference to Chart 4 gives the tabulated results of another series of tests which show an interesting comparison of the gain in capacity brought about by the increase in surface of the links and the proper distribution of the metal. The areas referred to are the actual areas of the fusible portion of the link and do not include the copper terminals which, as previously stated were identical in each fuse and consequently could be disregarded.

Having taken up the theoretical consideration of the subject and the calibration tests supporting some of the deductions, it is desirable now to consider the actual operation of the fuse under short-circuit. To permit of a full consideration of the phenomena shown at various intervals during the blowing of the

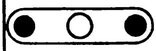
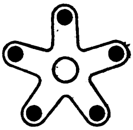
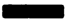
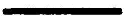
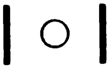
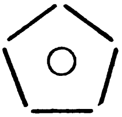
No. of Fuse	Style of Link.	Fuse Link Construction	Size of Link.	Volume Ratio	Amperes	Reduction in Metal Volume.
83	Single Wire		Diam. .164"	1.344%	80	Unit for Wire Links
106	2 Wire Multiple		Diam. .108" Each.	1.166%	80	13.22%
80	5 Wire Multiple		Diam. .063" Each.	.9919%	80	26.2%
88	Single Flat Strip		.063" x .3125"	1.253%	80	Unit for Strip Links.
86	Single Flat Strip		.028" x .625"	1.114%	80	11.1%
104	2 Strip Multiple		.0258" x .3125" Each	1.026%	80	18.1% Under No. 88. 7.8% Under No. 86.
105	5 Strip Multiple		.0095" x .3125" Each	.9447%	80	24.6% Under No. 88 15.2% Under No. 86

Chart 3

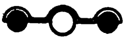
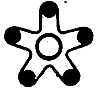
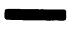
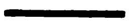
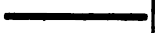
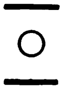
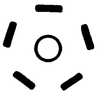
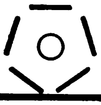
No. of Fuse.	Style of Link.	Fuse Link Construction.	Size of Link.	Area	Ampere Capacity
81	Single Wire.		Diam. .141"	1.33	60
96	2 Wire Multiple		Diam. .10"	1.88	73
80	5 Wire Multiple.		Diam. .063"	2.96	80
91	Single Flat Strip.		.100" x .1562"	1.537	65
90	Single Flat Strip.		.075" x .208"	1.856	67
87	Single Flat Strip.		.050" x .3125"	2.175	70
85	Single Flat Strip.		.025" x .625"	3.90	75
89	Single Flat Strip.		.0215" x .728"	4.50	75
97	2 Strip Multiple		.025" Thick .3125" Wide.	4.05	78
84	5 Strip Multiple		.025" Thick .125" Wide.	4.50	80
98	5 Strip Multiple		.0125" Thick. .25" Wide.	7.875	83

Chart 4

fuse under those conditions, an oscillograph was used. The resultant curves are given in Figs. 5 to 16, and the actual record of the tests, together with a drawing of an end-section of the links used in each case, with other important data relating to the test are given in Chart 5. The tests consisted in subjecting fuses, similar in every detail of construction, except as relates to the fusible portion of the link, to direct short-circuit across the bus-bars of a 6000-ampere-hour battery fed by one or more 500-kw. generators. The potential coil of the oscillograph was connected across the fuse rather than across the circuit, in order to show clearly the variations in the volts' drop at different intervals. An examination of these several curves gives a most interesting and instructive history of the complete cycle of events occurring within the fuse during its operation, all within a period of time considerably under 0.05 seconds.

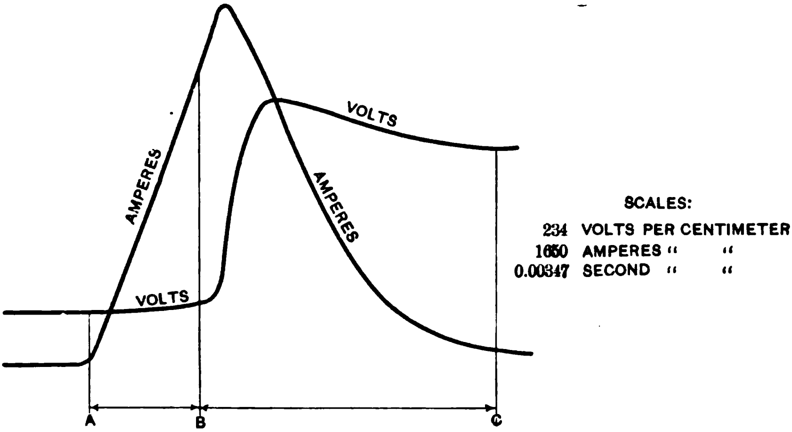


FIG. 5.—Five-wire multiple link 0.063 diam. capacity; 80 amperes. vol. ratio = 1 per cent

Referring to curve of Test IX, Fig. 12, as a good illustration, this may be analyzed as follows: This curve exhibits the operation of a five-strip multiple link fuse of 1 per cent volume ratio, 80 amperes capacity. Following the current curve, it will be seen that during the period *J A* the current is zero. At the instant *A*, the switch was closed and the current instantly rushed through the fuse, rapidly increasing in value until at *D* it had reached its maximum. It then begins to die away until at *C* it has become zero again, or in other words, the fuse has opened the circuit. Referring to the voltage curve from *K* to *Y*, the voltage as measured across the fuse is practically zero, that is to say, it was zero at *K* but at the beginning of the current flow, there was of course, a slight rise. This is, however, so small as not to be visible on the curve and for all practical purposes the voltage may be regarded during the interval *K Y* as zero. At the instant *Y*, the voltage begins to go up with great rapidity until it practically reaches its maximum at *I*; it then continues at almost even value until just before the rupture of the current, occurring at *C*, a slight inductive kick is noticed at *F*, after which it sharply declines and becomes constant at *M*, *M O* being the full voltage of the circuit across the fuse.

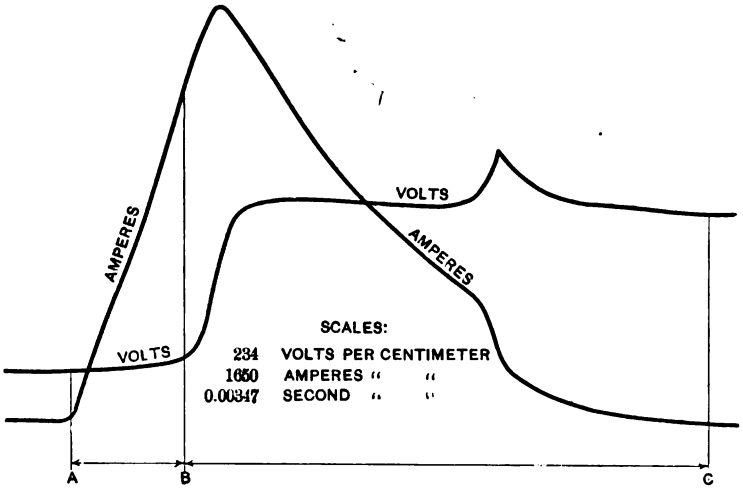


Fig. 6.—Single flat strip 0.028 x 0.625 wide. Capacity 80 amperes; vol. ratio = 1.12 per cent

Referring to the current curve, note the rapid rise of the current value from the point *A* to *E*. During that period, there was practically no voltage across the fuse. The actual time during which this rise in current was occurring, represented by the distance *A B*, is 0.0038 sec. It is during this interval that the fuse link is being raised to its melting point, the total energy impressed on the fuse being extremely small. From the point *E* on the current curve to its maximum value at *D*, the metal is being converted into vapor, and a corresponding rapid rise in voltage will be noted, showing the enormous increase in the resistance of the circuit. At *D*, the vapor begins to condense, or, in other words, lose its conductivity, and as the conductivity of the vapor path diminishes, the current falls. The voltage, however, continues to rise slightly, due to the same cause but remains practically constant from the point *I* until just before reaching the point at *F*. During this period the current is falling rapidly, and the total time or duration of fall is found to be 0.012 seconds. The maximum current which passes through the fuse is found to be 8415 amperes and the voltage at the same instant, found by measuring the height *H L*, was 304 volts, so that the power input into the fuse at the instant *G* is 2,558,160 watts, apparently an enormous amount of energy, but practically an instantaneous value. By integrating it is found that the average watts were 1,925,000 during the period that power was absorbed by the fuse. This period of energy input, is represented by the distance *B C*, and is found to be actually 0.0146 sec. from which is derived a value of 28,600 watt-sec. or a little over 27 B.t u. The total period of operation, or the time *A C*, which elapsed after the switch was closed, until the circuit was opened, was but 0.0184 sec.

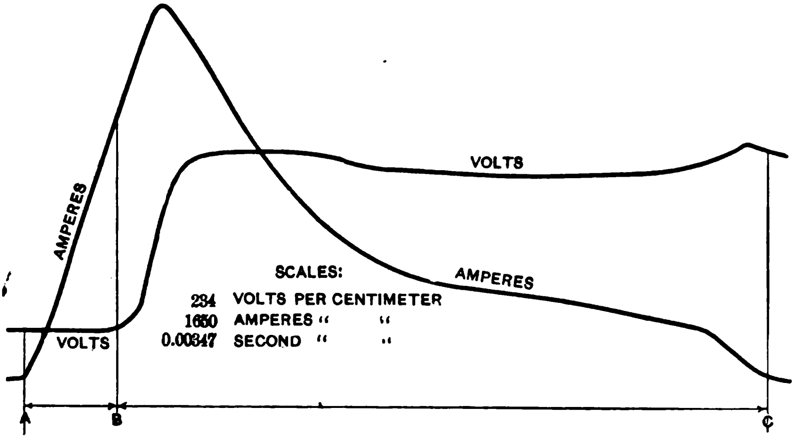


FIG. 7.—Single flat strip 0.050 x 0.3125 wide. Capacity 70 amperes; vol. ratio = 1 per cent

Referring to the curve, Test X, that of a single flat strip link fuse, it is noted that the time during which the link was being melted as represented by the distance *A B*, was practically the same as that of Curve IX of the previous test, but the significant feature lies in the relatively slow decline of the current value and the prolongation of the period during which energy was being absorbed by the fuse or the period *B C*. This time is actually 0.0246 sec. or an increase of 68 per cent in the period of operation of the fuse during which arcing was going on. By integrating the curve in precisely the same manner as that of Test IX, the average watts were found to be 2,360,000 and this value multiplied by the time, gives 58,000 watt-secs. or 57 B.t.u., an increase of the total energy input in excess of 102 per cent or more than double the total energy absorbed by the multiple strip fuse.

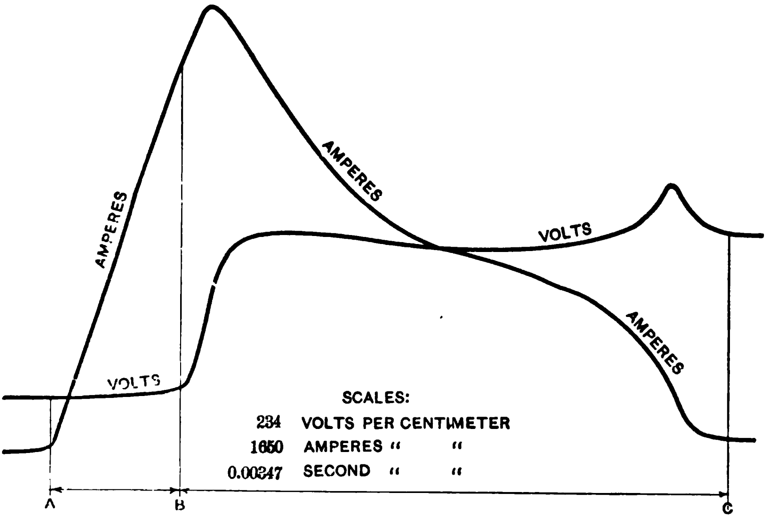


FIG. 8.—Single flat strip 0.030 x 0.625 wide. Capacity 83 amperes; vol. ratio = 1.19 per cent

A similar comparison of the other curves bears out in a most striking manner the important influence which the extension of the link surface and its proper distribution within the filling has in reducing to a large degree the total energy absorbed as well as the duration of the period of energy input. Comparing the results it will be found that the single link fuses invariably absorb more total energy.

The average energy input of the multiple link fuses tested was but 22,587 watt-seconds as compared with an average energy input of the single link fuses of 43,746 watt-seconds; that is to say, the single link fuses absorb practically double the energy. It should be further noted that even disregarding the fact that in several of the single link fuses, the explosion of the fuse materially shortened the period of power input, the average period of power input of the single link fuses is 72 per cent greater than the same period for the multiple link fuses.

Furthermore, in anything like equal ampere capacity the maximum current flow was greater with the single link fuses, the average excess being 15 per cent. This has an important bearing on the tendency to disrupt or burst the cartridge, since the greater the current, the more rapidly is the link raised to its boiling point and consequently the greater the rate of development of internal pressures. In all enclosed fuses provision is made for the escape of these gases. It will be apparent, therefore, that the rate of development of the gas must be considered, since in one case the rate of escape might be such as to prevent the ultimate bursting pressure being reached, whereas in another fuse of exactly the same metal volume, the rate of development of pressure might be so much more rapid than

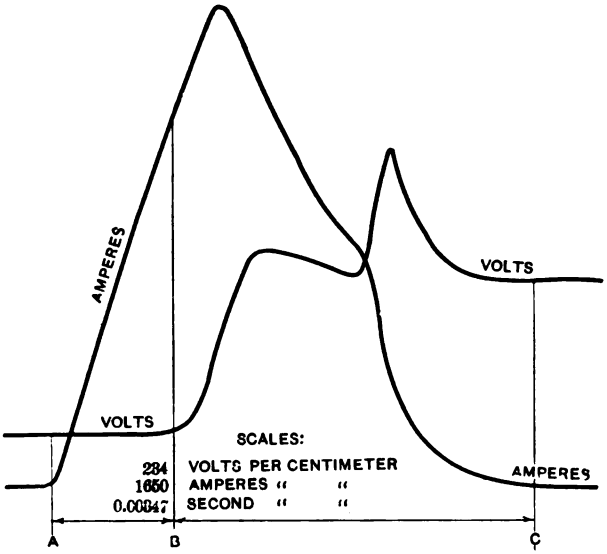


Fig. 9.—Single round wire 0.164 diam. Capacity 80 amperes. Vol. ratio = 1.35 per cent

its rate of escape that the bursting pressure would be rapidly reached.

I would briefly summarize the results of the other tests as shown in tabulated form in Chart 5 and the analyses of the other curves may be briefly summarized as follows:

Tests 1 and II (Figs. 5 and 6) compare the operation of a five-wire multiple link fuse and a single-strip flat link fuse of the same ampere capacity. By reference to Chart 5 it will be seen that the operation of the single flat link fuse was explosive and dangerous, whereas the multiple link fuse operated quietly. Comparison of these curves confirms this most forcibly. It will be noted that the period *A B*, during which the metal was being raised to its melting point, was practically the same for both fuses, but the period *B C*, during which energy was being absorbed by the fuse, is extended in a most pronounced manner in the single link and that the total energy absorbed was about 120 per cent greater.

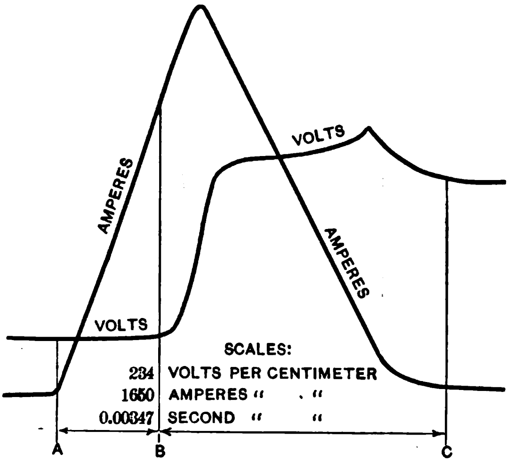


Fig. 10.—Five-strip, multiple link 0.0125 x 0.250 wide. Capacity 83 amperes. Vol. ratio = 1 per cent

Test III (Fig. 7) showing the operation of a single flat strip fuse of the same volume ratio as Test I but of a smaller ampere capacity, exhibits an extension of the period of energy input *B C* even in a more pronounced manner. The total energy absorbed in this fuse was nearly 140 per cent greater than with the multiple link.

In Tests IV and V (Fig. 8) we compare the operation of the five-strip multiple link fuse and the single-strip link of the same ampere capacity with the five-wire multiple link of the earlier test. Unfortunately the film record of Test IV was torn so that it was impossible to compare the curves. The record shows, however, that the multiple strip operated quietly, while the single strip exploded and one may judge of the characteristics of the curve of the multiple strip by reference to Test VII (Fig. 10) which was the curve made from a fuse of identically the same construction. The same characteristics are here presented as in Test I.

In Test VI (Fig. 9) is shown the operation of a single wire link fuse. This curve is particularly interesting as showing the effect of concentrating a mass of metal in as compact form as possible, thereby reducing to a minimum the avenues of escape of the gases within the filling. The rise of the current wave is more pronounced than in any of the other single link fuses, the current here reaching a maximum of 10,642 amperes. While the period of energy input, *B C*, is relatively short. This is due to the fact that this fuse exploded with greatest violence and the current was actually ruptured by the explosion. This is indicated by the very pronounced inductive kick shown on the curve, the rise in potential at the instant of rupture being about 450 volts.

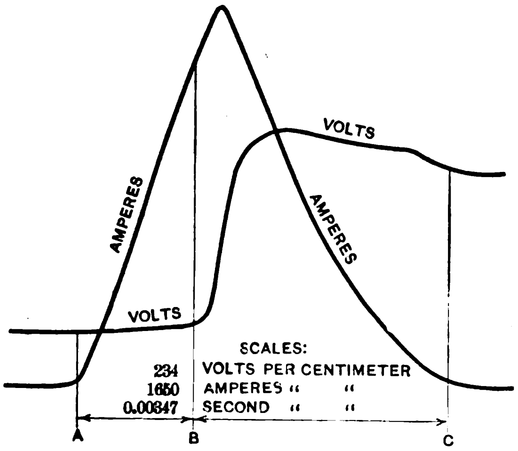


Fig. 11.—Two-strip multiple link 0.025 x 0.3125 wide. Capacity 78 amperes. Vol. ratio = 1 per cent

In Test VIII (Fig. 11) is shown the operation of a two-strip multiple link of slightly less capacity than that used in Test VII, its operation being most satisfactory in every way.

Tests IX, X and XI (Figs. 12, 13 and 14) give the comparative operation of two single-link fuses and a five-strip multiple link at 600 volts as distinguished from 500 volts heretofore used. Again the multiple link operated quietly, whereas the two single-link fuses exploded.

Test XIII (Fig. 15) records the behavior of the curve of a fuse, where the explosion did not interrupt the current promptly but where the arc was maintained for a brief interval. The variations in the voltage during the period of arcing are here most pronounced.

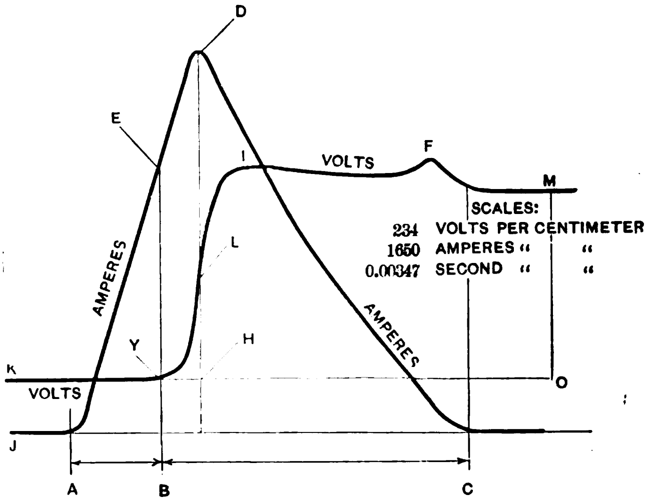


Fig. 12.—Five-strip multiple link 0.025 x 0.125 wide. Capacity 80 amperes. Vol. ratio = 1 per cent

In Test XV (Fig. 16) is shown the operation of a five-strip multiple link with a slight inductive resistance in the circuit. In comparison with other multiple link curves, the prolongation of the period *A B* is most marked with slower and less abrupt rise of the potential. The fuse operated perfectly although giving indications of the phenomena shown.

Another important consideration is the concentration of the energy at one point in a single-strip fuse as compared with its division in the multiple-link fuse. An interesting illustration of this particular feature is found in Tests I and II. The fuse of Test I was a five-wire multiple link, the total resistance of which was 0.0017 ohms or the resistance of each element was 0.0085 ohms. The maximum current flow through this fuse, the record shows was 7600 amperes, from which it is obvious that the energy required for raising the metal to the boiling point of each element was 19,650 watts or a total for the fuse of 98,250 watts. Compared with the single-strip link of Test II, the resistance of which was somewhat lower on account of its greater volume ratio, being 0.0015 ohms, the maximum current flow was seen to be 8910 amperes, giving a total power input of 123,700 watts. In other words, 25,000 more watts were absorbed by the single link fuse at the period of maximum current flow than by the multiple link, and further than that all of this energy was developed at one plane at the center of the fuse, whereas with the multiple link but 19,650 watts was developed in each element; that is to say, there was over six times as much energy developed at one point of the single link fuse as in the multiple link.

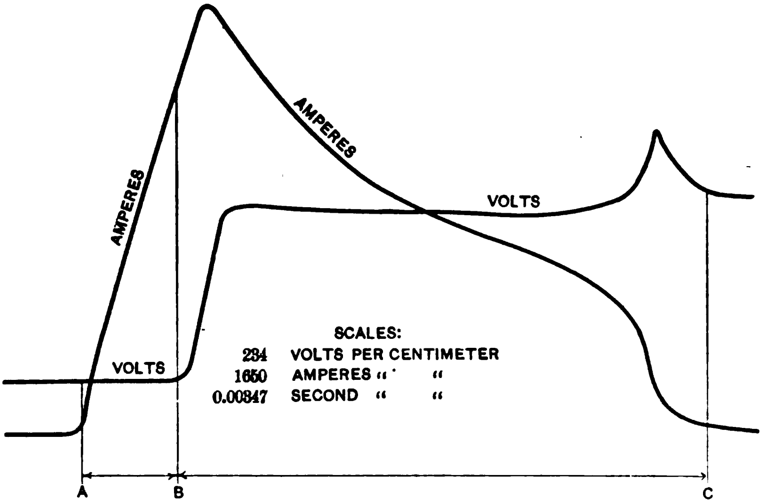


FIG. 13.—Single flat strip 0.028 x 0.625 wide. Capacity 80 amperes. Vol. ratio = 1.12 per cent

Now under such conditions it must be realized that there exists in the flat link fuse a hole or tunnel through the filling, being the space formerly occupied by the metal of the link, which is momentarily filled with a conducting vapor. The conductivity of this vapor is dependent very largely upon its density. In this concentration of a relatively large amount of vapor within an extremely confined space, and consequently of relatively great density, is found one explanation for the greater current flow seen in every instance in the single-strip link. With the multiple-link fuse we have five tunnels distributed at wide intervals within the tubing, the energy in each one being but one-sixth that in the single tunnel of the other fuse. Moreover, it has been shown that with the single link fuse, the vapor has to travel approximately twice the distance in order to bring all the filling into action as a condenser, and consequently requires more time than with the multiple fuse. Therefore, with the single link fuse, there is a rapid accumulation of pressure and a pronouncedly greater current flow, or an accumulative effect resulting in the disruptive action noted.

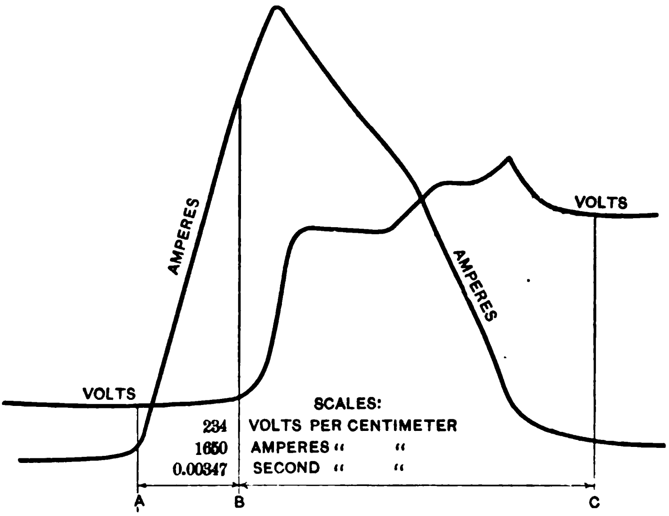


Fig. 14.—Single flat strip 0.063 x 0.3125 wide. Capacity 80 amperes. Vol. ratio = 1.26 per cent

The statement may be made in making these comparative tests, that possibly the most efficient form of single link fuse is not used, and that the area might be extended by using a greater width and folding up the edges, etc. In this connection it should be pointed out that such modifications could hardly affect the results, since if such a peculiar form of single link fuse were employed, the same form could, of course, be used in the elements of the multiple strip for comparison, and the gain,

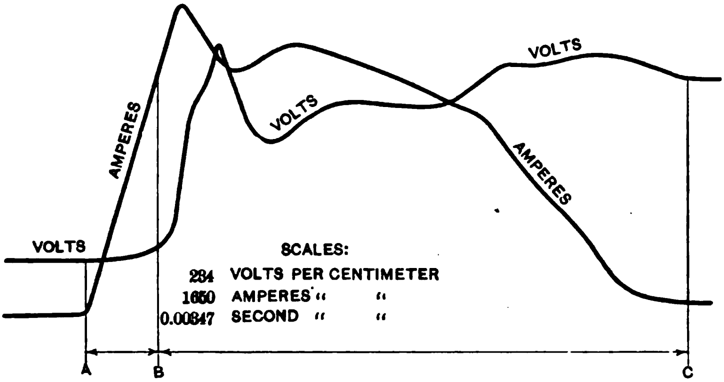


Fig. 15.—60 amperes, 600-volt. Single flat-strip link

both in area and distribution, would remain relatively the same. Further than that, it is difficult to conceive of any arrangement of the single link whereby all the mass of the filling could be so promptly and effectively brought into action.

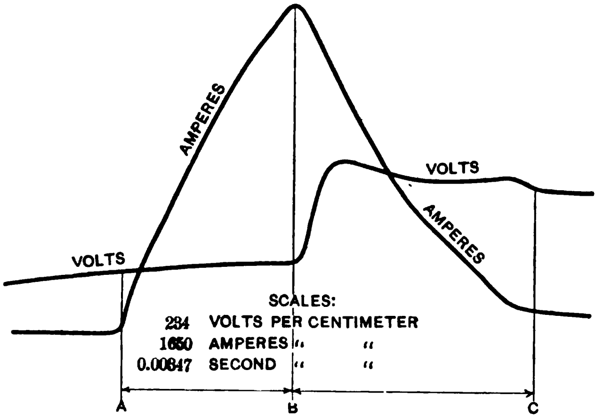


Fig. 16.—Five-strip multiple link 0.025 x 0.125 wide. Capacity 80 amperes. Vol. ratio = 1 per cent

Two other possible causes contributing towards the explosive action of a fuse have been suggested, one, in the presence within the filling of a certain percentage of moisture and within the casing of a certain amount of air which, it was claimed, was

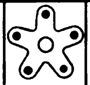
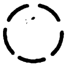
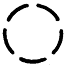
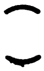
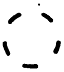
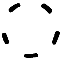
Test Number	Fuse Link Construction	Capacity Amps Volts	Volume Ratio of Fuse Link	Maximum Amperes	Time of Melting A. B.	Time of Arcing B. C.	British Thermal Units	Operation.
I		80 500	1%	7600	.0052	.0135	16.6	Quiet and satisfactory. Cartridge uninjured.
II		80 500	1.12%	8910	.0052	.0243	36.55	Explosive and dangerous. Cartridge injured at one end.
III		70 500	1%	8170	.0045	.0302	39.88	Explosive and unsatisfactory. Cartridge injured at one end.
IV		83 500	1%	—	—	—	—	Quiet and satisfactory. Photographic record lost. Cartridge uninjured.
V		83 500	1.19%	9570	.0059	.0253	48.78	Explosive and dangerous. Cartridge injured at one end.
VI		80 500	1.35%	10642	.0055	.0166	32.8	Explosive and very dangerous. Cartridge burst.
VII		83 500	1%	8420	.0048	.0132	22.9	Quiet and satisfactory. Cartridge uninjured.
VIII		78 500	1%	8170	.0052	.0118	18.9	Satisfactory. Cartridge uninjured.
IX		80 600	1%	8420	.0034	.0146	27.0	Satisfactory. Cartridge uninjured.
X		80 600	1.12%	9390	.0042	.0246	54.94	Explosive and dangerous. Cartridge burst.
XI		80 600	1.26%	9650	.0048	.0163	35.8	Explosive and very dangerous. Cartridge burst.
XIII		60 600	—	6520	.0035	.0243	44.42	Explosive and very dangerous. Cartridge burst. Base broken.
XV		80 600	1%	—	—	—	—	Quiet and satisfactory.

Chart 5.

suddenly and rapidly expanded by the heat of the arc. An examination of the filling of the ordinary fuse will show that there can be no material amount of air, the heating of which would occasion the violent explosions resulting from short-circuit, particularly when it is considered that the metal generally used for the link expands over 2400 times when converted from its metallic form to vapor. By actual measurement it is found that the total volume of air present in the average enclosed fuse is in the neighborhood of 19 per cent of the filling used.

The presence of water might cause serious disturbance were there a sufficient amount of it converted into steam, but this would require the heating of the entire mass of filling to a high temperature; and to raise it to this temperature in the extremely short interval of time which is required to operate the fuse, would call for the application of a tremendous amount of heat energy. Of course if the arc should be maintained, the filling would rapidly reach such a temperature, but the condition under consideration is one where the fuse explodes when it is short-circuited, and as there can be no prolonged maintenance of the arc under this explosive action, which would affect the filling, it could not be heated in that manner and the only heat which could be applied to that particular purpose is that absorbed by the fuse in converting the metal of the link into its vapor. Actual measurement was made of the percentage of moisture present in the filling, both before and after a fuse had been subjected to a severe short-circuit which it had handled satisfactorily. Starting with an initial amount of 5 per cent, nearly 3 per cent remained, showing that but a little over 2 per cent of the total moisture had been driven off; namely, that portion of the moisture present in the filling which was quite close to the metal of the link.

While there are unquestionably various methods by which relatively the same effects may be produced as by the use of the multiple link, such, for example, as the well-known cigarette fuse or the cylinder link, it will be seen that these are but the amplification of the same principles; namely, extreme extension of surface and such an arrangement of the metal that the greatest possible contact with the filling is provided, to increase to the greatest degree the avenues of escape of the gases.

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THE MODERN TELEPHONE CABLE

BY FRANK B. JEWETT

To those not closely in touch with the telephone situation to-day, the importance of the modern telephone cable may be indicated by stating that of the 8,000,000 miles of wire in the exchange plants of the Associated Bell telephone companies, more than 6,800,000 miles are in the form of underground, aerial, or submarine cable. These figures refer solely to the wire used for outside construction and do not include the thousands of miles of wire in cable form employed in central offices or the wiring of large buildings.

At the present time the bulk of the cable in any telephone plant is used in connection with exchange construction in urban districts. For a large part of such work the concentration of hundreds of circuits in the form of cables is the only available method of providing the facilities necessary to meet present-day service demands, which in many of the larger cities exceed one telephone for each 20 inhabitants, and in a few cities more than one for each 10 inhabitants.

It should be clearly recognized, however, that even the best cable circuit is much less efficient than an open-wire circuit; for example, one mile of the No. 19 B. & S. gauge cable circuit ordinarily employed in exchange construction results in as much current attenuation as 35 miles of No. 8 B. W. G. open-wire copper toll circuit, or 3.5 miles of the smallest size open-wire iron circuit used in rural exchange work. From these figures it is apparent that the extensive use of cable necessarily results in a material reduction of the radius within which satisfactory commercial transmission can be given, and as the most advanced telephone art to-day is only with difficulty meeting the increasing demands for long-distance service, cables can be substituted for open wires only when the further maintenance of open-wire circuits becomes impracticable. It is on account of this decrease in efficiency that the telephone company expends such large sums to retain open-wire circuits for its toll lines as close as possible to the central office, but even in this portion of the plant increasing numbers of circuits have forced the abandonment of pole lines in certain situations.

In another direction also the necessity for cable construction has developed to a certain extent; namely, providing the necessary circuit facilities between very large cities separated by moderate distances and between which there is a great deal of terminating telephone business; thus at the present time the business between New York and Philadelphia, New York and New Haven, and Chicago and Milwaukee, is handled over all-cable circuits.

The extensive application of cable construction in the modern telephone plant just outlined has been made possible only through the development of a form of cable exceedingly efficient as compared with the earlier forms. It is the purpose of this paper to consider a few of the essential requirements which have had to be met in the production of such a cable. While certain features of the manufacturing processes are described in order to explain the method of obtaining certain characteristics, the paper is in no sense an exposition of the technique of cable manufacture. In order to show how the telephone engineer ensures the production of a cable having the desired characteristics, clauses covering the points discussed have been taken from the standard form of cable specifications employed by the Associated Bell companies.

THE ESSENTIAL REQUIREMENTS OF THE MODERN TELEPHONE CABLE

The essential requirements for an efficient and satisfactory telephone cable, while primarily electrical, are of course unavoidably connected with mechanical and cost restrictions. These requirements, which must be fulfilled by the cable and which form the basis of present-day cable specifications, are briefly as follows:

1. That the cable shall provide the maximum number of independent and non-interfering circuits within the minimum space.

2. That these circuits shall have the maximum transmission efficiency for currents of telephonic frequency, compatible with the other electrical and mechanical requirements.

3. That the dielectric strength of the cable shall be such as to ensure against failure from any of the potentials normally employed and to make possible its protection against damage from lightning and from foreign circuits operating at potentials in excess of those employed on telephone lines.

4. That the mechanical arrangement adopted to obtain the necessary electrical properties shall be such as to insure a continued maintenance of these properties after the cable has been installed. This assumes a construction which will withstand the hard usage unavoidably connected with cable installation.

5. That this mehanical construction shall be made at a cost which will render the cable circuits economically available in comparison with other known means of circuit provision.

In addition to the foregoing, certain subsidiary requirements dealing with the general size of the cable desired; that is, the size of wire and number of pairs required; the method of circuit identification (color scheme); the length of cable sections to be furnished; the method of preparation for shipment and some form of guarantee which will insure high-grade material and workmanship in the manufacture of the cable, are ordinarily covered in the cable specification,

Standard cable construction. While differing somewhat in details, the essential features of all modern telephone cables, known as dry-core paper-insulated, are the same whether the wires are in the little five-pair or ten-pair subscribers' cables ordinarily strung on pole lines or in the largest sizes employed underground. Cables of this type are in one respect fundamentally different from cables which employ rubber or gutta-percha insulation. In the latter construction the dielectric which surrounds the wire serves not only to keep the wires in proper position, but being itself impervious to moisture, the dielectric serves to maintain the efficiency of the circuit, whether exposed to moisture or not. The telephone cable, on the other hand, belongs to that class of cables in which any solid dielectric employed is used primarily as a mechanical separator or to give the requisite dielectric strength. In this class of cables the deleterious effects of moisture are guarded against by surrounding the conductors with a water-tight metallic sheath.

For making up telephone cables, wires of the proper size are first insulated by wrapping them individually with dry paper ribbon. This ribbon, which is usually about $\frac{5}{8}$ in. wide and of a thickness varying from 0.002 in. upward depending on the size of the wire, and colored in some distinctive fashion, is spirally applied, but not with such a tension as to cause it to adhere closely to the wire. For the ordinary underground or aerial cable a single wrapping of paper suffices; in some forms of submarine cable two wrappings of paper, laid on in reversed directions, are used. In any event, the ribbon is overlapped sufficiently so that the wire is completely covered. Thus insulated, the wires are twisted together in pairs, the two wires of a pair being insulated with different colored papers and the length of twist depending upon the size of the conductors and the use to which the cable is to be put. The maximum length of twist, however, rarely exceeds 6 in. and for the smaller sized wires is ordinarily under 4 in. This twisting of the individual circuits is for the purpose of neutralizing inductive and capacity effects, which would occasion " crosstalk " between the various circuits if the wires of the core were laid up parallel to one another.

The core of the cables is made up in cylindrical form by assembling the requisite number of twisted pairs together in concentric layers one or more pairs thick, the pairs in each layer being arranged spirally about the axis of the core and the direction of rotation in the alternate layers being reversed. As explained below this use of a concentric layer construction is adopted to ensure the necessary mechanical stability for the completed cable. The number of pairs in each layer is dependent upon the size and capacity of the cable required and is varied by changing the size of the central strand.

When the cylindrical core has been completed, it is wrapped with one or more thicknesses of paper tape to bind the conductors firmly in place, present a smooth exterior surface, and prevent the lead of the sheath from coming in contact with the insulation of the outer layer of conductors. This wrapping also gives the higher dielectric strength needed in the pairs of the outer layer. During the process up to this point the paper, being hygroscopic, has unavoidably taken on more or less moisture which must be removed before the sheath is applied. To this end the core, suitably reeled, is placed in a drying oven in which air at a high temperature is circulated for a considerable period, after which the core is taken immediately to the lead press and the final sheath applied. This completes the process except for the testing, sealing of the ends and reeling for shipment.

While the individual wires forming the core of the cable just described are wrapped with paper, the cable is essentially different from the ordinary paper-insulated power cable, in that it is in effect an air-core construction. The paper, which is loosely applied and fills only a part of the total space not occupied by the conductors, is deformed in the process of cabling and serves merely as a mechanical separator to keep the wires apart and not as a dielectric *per se*, or as the carrier for a dielectric compound. In cable of this type the real dielectric is the dry air between the wires.

To show how nearly the present dry-core cable meets the essential requirements of the telephone industry, it may be interesting to examine some of these requirements and their actual fulfilment in detail and also the evolutionary process by which the present form of construction has been arrived at.

Choice of the dielectric.

Specification requirement: Each conductor shall be insulated with a single wrap of paper spirally applied.

In designing a cable for high-frequency current transmission work the principal requirement, as previously noted is that it shall combine the maximum number of independent non-interfering circuits having a maximum of transmission efficiency within the minimum space and at a minimum cost. It is essential, therefore, that the dielectric selected for maintaining the proper separation of the wires and providing the necessary mechanical properties required of the cable should have both a low dielectric capacity and small dielectric hysteresis. These features, which in power cables designed for transmitting large amounts of low-frequency, high-potential current may be of secondary importance compared with high insulation and high dielectric strength, become paramount when the question is one of securing an efficient cable for the transmission of small currents having frequencies ranging up into the thousands of periods per second, and in which high dielectric strength is a matter of secondary consideration. The importance of these characteristics of the dielectric are readily apparent when we come to examine the mathematical expressions for the propagation of high-frequency currents such as those met with in telephony.

For a uniform metallic circuit containing resistance, inductance, capacity and leakage uniformly distributed, the formula for the attenuation constant is

$$a = \sqrt{\tfrac{1}{2}\sqrt{(R^2+L^2\,\omega^2)\ (S^2+C^2\omega^2)} + \tfrac{1}{2}\,(R\,S - L\,C\,\omega^2)}$$

In this formula R, L, and C have the ordinary significance, being respectively the resistance, inductance, and shunt capacity expressed in ohms, henrys and farads, while ω has the ordinary significance, being $2\,\pi$ times the frequency, and S, which represents the shunt leakage in parallel with the shunt capacity, expressed in mhos, is a measure of the combined direct-current conductance as determined from the insulation of the cable and also of the apparent conductance which results from the energy loss due to dielectric hysteresis.

For telephone cables where the wires are close together the inductance is negligibly small and the formula reduces to

$$a = \sqrt{\frac{R}{2}\left(\sqrt{S^2 + C^2\,\omega^2} + S\right)}$$

or when the leakage component is small in comparison with the capacity component, to approximately

$$a = \sqrt{\frac{R\,C\,\omega}{2}}\left(1+\frac{S}{2\,C\,\omega}\right)$$

This is the formula which' ordinarily applies to cable circuits employed for telephonic transmission, and it will be noted that where S is zero; that is, for cables having high insulation and no dielectric dissipation, the expression for the attenuation constant is merely that of the so-called "$K\,R$ law." The quantity $\frac{S}{2\,C}$ in the above formula, known as the "damping constant," is dependent on the dielectric of the cable and is independent of the capacity of the cable provided the dielectric is unchanged in character by changing the separation of the wires. In order, therefore, that the transmission efficiency of any cable shall be high for some particular frequency or range of frequencies, it is necessary that in addition to low capacity, the dielectric shall have the smallest possible ratio of shunt conductance to shunt capacity for these frequencies.

In the following table are given the constants at one thousand periods per second for No. 19 B. & S. gauge cables made up with rubber insulation, braided-cotton insulation impregnated with paraffin, and dry-core paper insulation. In each case the cables have the constants normal to the particular kind of construction. From this table it will be noted that for rubber-insulated and cotton-impregnated-insulated cables both the capacity and conductance are materially higher than in the dry-core, paper-insulated cable.

CONSTANTS OF NO. 19 B. & S. GAUGE TELEPHONE CABLES

Insulation	Mutual capacity mf. per mile 1000 p.p.s.	Mutual conductance m. mhos per mile 1000 p.p.s.	Damping constant $S/2C$ 1000 p.p.s.
Rubber................	0.15	40	133
Braided cotton filled with paraffine...........	0.12	16	67
Dry-core paper.........	0.08	2	12.5

Taking the constants of the foregoing table and applying them in the approximate formula, it will be seen that the attenuation constant of the impregnated cable is 24 per cent, and that of the rubber 40 per cent, higher than that of the dry-core paper cable; also that while the dissipation of the dielectric increases the attenuation in the latter cable by less than 0.2 per cent at 1000 periods per second, that in the impregnated cable increases it by 1.05 per cent and in the rubber insulated cable by 2.10 per cent. In addition to the effect of dielectric dissipation increasing the attenuation of the cable, the fact that this increase is not constant for all frequencies but it is greater the higher the frequency, results in a cable with high dielectric dissipation having more distortion than one in which the dissipation is low over the range of frequencies involved in speech transmission.

From the above table it is also evident from the small value of the dissipation constant for the dry-core cable that with this type of construction conditions have been attained approximating very close to those in which nothing but air would intervene between the wires. In addition to the numerous mechanical, electrical, and economic defects which obtained in impregnated and rubber-cored cables, the fact that they were materially inferior in efficiency to the present type of dry-core construction was one of the principal factors leading to the adoption of the latter.

While the standard telephone cable of to-day is essentially an air-core cable, the amount of solid dielectric necessary for mechanical reasons is appreciable, and in specifying a wrapping of high-grade dry-rope paper ribbon the aim has been to utilize a material which will have the lowest possible dielectric capacity and dissipation, and at the same time possess the necessary mechanical properties to permit of its use in comparatively small quantities. That the paper should be spirally applied to the wires rather than put on in some other fashion, is the result of actual experience with other types of construction. In the early days of dry-rope paper insulation, numerous schemes for applying the paper were suggested and tried, with the result that spiral application was found to afford the greatest immunity from accidental crosses during installation while at the same time requiring a minimum amount of solid material in the core.

Insulation resistance.

Specification requirement: In every length of cable each conductor shall show an insulation resistance of not less than 500 megohms per mile of cable at 68 degrees fahr., each conductor being measured against all the rest and the sheath.

For telephone cables made in the United States the foregoing requirement is the one ordinarily specified. In Europe the insulation requirements are frequently very much more severe than this, and sometimes necessitate drying the cable after it is laid and spliced.

It is extremely doubtful however, whether a high insulation specification can be justified in view of the extra expense incident to meeting it and the exceedingly small improvement in transmission resulting therefrom. The result of American practice has indicated that the specification of an insulation resistance which will ensure honest manufacturing processes, a reasonable amount of drying and a permanent product, is all that is warranted. As a matter of fact the regular drying processes adopted ordinarily give an insulation resistance materially above 500 megohms, although under the exceptionally humid conditions frequently prevailing in the summer months, the insulation at times approaches the specification figure.

An inspection of the foregoing attenuation formula and the constants for different dielectrics will show at once that high insulation is not in itself necessarily an indication that the cable will be efficient. Thus rubber-insulated cables which have an insulation resistance of thousands of megohms per mile are decidedly less efficient than dry-core cables of the same capacity whose insulation is 500 megohms per mile. Since the principal dielectric loss in a dry-core cable results from dielectric hysteresis, rather than from direct conduction the specification of an insulation resistance requirement must, as previously stated, be looked upon primarily as one to insure an efficient process of manufacture and provide for a cable core which will not be subject to deterioration. The effect of this drying on the insulation and dielectric constant of the cable is shown in the following table of measurements made on a cable core before and after immersion in the regular drying tank. It will be seen that while the insulation has been improved materially by the removal of moisture the great improvement so far as efficiency is concerned has come from the reduction of the dielectric capacity and dielectric hysteresis in the cable.

EFFECT OF DRYING PAPER CABLE
300 pair No. 19 B. & S. Gauge.

Insulation megohms per mile		Mutual capacity mf. per mile		Damping constant $S/2C$ (1000 p.p.s.)	
Green core	Finished cable	Green core	Finished cable	Green core	Finished cable
300	1550	0.082	0.071	19	12

Thus while the transmission efficiency has been increased 7.1 per cent by the process of drying, the improvement due directly to the increased insulation resistance is less than 0.001 per cent, that due to the reduced capacity being 7.0 per cent and that to the reduced damping constant 0.1 per cent. As to whether further drying would not result in still further improvement it can be said that beyond the period of drying ordinarily employed, the dielectric capacity and damping constant of paper show but little further reduction even with the most elaborate drying by chemical processes. Such processes, on account of their expense, could probably never be justified in any but exceptional cases.

Dielectric strength.

Specification requirement. The insulation of each conductor shall be capable of withstanding a potential of 500 volts without rupture.

All dry-core paper-insulated cables used by the Associated Bell Telephone Companies are required to withstand a direct-current potential of 500 volts between any wire and its mate, or between any wire and all of the remaining wires and the sheath of the cable. As noted previously, this requirement is incorporated not only to guard against the danger from failure due to the normal potentials met with in telephone operation, but chiefly that the cable circuits may be efficiently protected from lightning or when they come in contact with light or power circuits. Past experience has shown that efficient protection without unduly great maintenance charges can be obtained only by providing open space cut-outs which will operate at potentials lower than the break-down potential of the cable. As it is not feasible to maintain open space cut-outs with operating potentials much below 500 volts, this figure marks the minimum dielectric strength which admits of suitable protectors. For certain classes of cables, where the exposure conditions either to power circuits or to lightning are exceptionally severe, or where, as at submarine cables crossing in the center of long toll lines, the inability to quickly clear trouble or repair damage would involve serious interruptions of service, special high dielectric requirements are frequently specified.

Electrostatic capacity.

Specification requirements: In every length of cable the average mutual electrostatic capacity of all the pairs and the mutual electrostatic capacity of any pair, per mile of cable at a temperature of 68 degrees fahr. shall not exceed the values given in the following table, the capacity shall be measured between one wire of a pair and its mate, the remainder of the conductors being connected to the sheath.

For cables used in exchange construction, such for instance as No. 19 gauge of 300 pairs or less, the mutual capacity referred to in the above quotation ordinarily averages slightly below 0.080 mf. Thus for a 300 pair No. 19 B. & S. gauge cable the specification average is 0.077 mf. and the maximum 0.084 mf. per mile for each length, while for cables of 240 pairs or less the corresponding figures are 0.070 mf. and 0.079 mf. respectively.

In the foregoing specification requirements the capacity is that measured by the ordinary charge or discharge method. While this constant is not that directly applicable to the computation of transmission efficiency for high frequencies, it is justified in manufacturing specifications on account of the difficulty of making accurate high-frequency determinations. It is also justified by the fact that in a thoroughly dried cable the capacity determined by the discharge method is not greatly in excess of the high-frequency capacity. This is indicated by the following table which gives the capacities of a small condenser having a cable paper dielectric 0.0085 in. thick, before and after the latter had been subjected to the ordinary drying process. It will be noted that in the undried state the difference between the discharge and high-frequency capacities is large. In a properly drawn specification the capacity requirement is a check on the insulation requirement as a guarantee of proper drying, it being impossible to provide the requisite number of pairs having the proper capacity in the specified sheath with an insufficiently dried core and still maintain the requisite dielectric strength.

EFFECT OF DRYING CABLE INSULATING PAPER.

Condition of paper	Thickness of paper	Capacity of condenser micro-microfarads		
		Discharge	1000 p.p.s.	2000 p.p.s.
Undried.......	0.0085 in.	11000	7020	6953
Dried.........	"	5793	5780	5779

With dry-core paper construction by a proper cabling of the pairs, the capacity of the cables can be varied at will within a moderate range to meet different transmission conditions, while at the same time retaining the necessary mechanical and electrical properties. Owing to irregularities in manufacture and differences in location within the core, all the pairs do not have exactly the same capacity. For this reason, it is customary to specify both an average mutual capacity limit for all the pairs in each length and also the maximum mutual capacity limit of any single pair. This insures the proper efficiency for the completed cable run without putting such a stringent limitation on the uniformity of the product as to render the cost excessive.

It is now customary to specify mutual rather than grounded capacity, as the former is a constant of the cable directly indicative of its transmission efficiency. So far, however, as ensuring efficient construction and good workmanship are concerned, either mutual or grounded capacity would suffice, since within the range of capacities ordinarily met with in telephone cables the relation between the mutual capacity of a pair and the grounded capacity of its component wires is fairly constant, the mutual capacity being approximately 60 per cent of the grounded capacity.

If an attempt is made to secure too low a capacity by separating the wires and employing too small an amount of paper, the core becomes so soft that the completed cable is easily deformed, and consequently extremely hard to handle; on the other hand, any attempt to secure an extremely high capacity by putting an excessive number of pairs in the core renders the cable stiff and unwieldy, or if the amount of paper is sacrificed the dielectric strength will be unduly low. Experience has shown that an average mutual capacity of about 0.050 mf. per mile marks the lower limit for single-wrap paper cable which can be readily handled without undue deformation, while approximately 0.09 mf. per mile marks the upper limit. Between these two limits practically any desired capacity can be obtained, although on account of having to conform to a limited number of cabling schemes it is not always possible to secure a uniform gradation of capacity with a specified sheath diameter and number of pairs.

Sheath.

Specification Requirement: The core shall be enclosed in a sheath composed of an alloy of lead and tin, the amount of tin by weight to be not less than 3 per cent. The sheath shall be free from holes or other defects and shall be of uniform composition and thickness. The thickness and outside diameter shall be for any size of cable as called for in the table given below.

For the mechanical protection of the core wires during and after installation and for preventing the ingress of moisture at all times, a continuous sheath composed of an alloy of lead and tin is molded firmly about the finished and dried core. This sheath, which varies in thickness from $\frac{1}{12}$ in. to $\frac{1}{8}$ in. for aerial and underground cables, depending upon the size of the core, is molded in a continuous section over each individual length of core immediately on the removal of the latter from the drying oven.

To ensure uniformity of practice in the cable plant it is necessary to set some limit on the maximum diameter of the sheath. At the present time the standard for a full size cable is $2\frac{5}{8}$ in. outside diameter, this being the limiting size that can be satisfactorily drawn into a standard 3 in. duct. A cable of this size will contain 300 pairs of No. 19 B. & S. conductors having the capacity noted above.

No single problem connected with the development of the modern telephone cable has probably been so difficult of solution as deciding upon the proper type of sheath, and the brief specification clause quoted above embodies the results of years of experience. Unlike most of the other features of the cable, the proper requirements for the sheath could not be forecast to a large extent and many indeed have resulted from conditions developed since the use of cable was first begun.

At the time when impregnated-cotton-insulated cable was the standard construction, the sheath was formed up separately and the core drawn in. This necessitated a considerable amount of clearance between the sheath and the core and although the entire inner space was ultimately filled with paraffin or resin oil, the cable had a decided tendency to buckle and crack if bent on any except a long radius. For this reason and because it was frequently necessary to relocate cables in the plant, early specifications usually contained a clause stating that the completed cable must be capable of being wound and unwound a certain number of times on a drum of specified diameter without buckling or cracking. This requirement was to ensure the cable being serviceable when withdrawn from the duct.

The process also limited the length of sheath which could be continuous, so that where long lengths of large cable were needed to fit suitable manhole spacings, factory joints in the sheath had to be resorted to. The care in making these so as to withstand the rough treatment incident to pulling into the duct was such as to greatly increase the difficulties and expense of manufacture. As a result of the defects in the earlier forms the present process was developed of moulding the sheath directly on to the dried core so as to closely fit it, eliminating at once the necessity for factory joints and the need for clearance between the core and sheath.

The specification of a 3-per cent tin alloy for the sheath is likewise a result of experience gained in the early days of cable development. Added primarily for the purpose of hardening the sheath so as to better withstand rough usuage during manufacture and installation, the amount of tin used was long a matter of individual preference. The present standard requirement was only arrived at when a careful investigation was made to determine the proper remedy for the cracking of aerial cable sheaths, which developed when the sheath was subjected to continued vibration. At the time there was a very strong sentiment in favor of a pure lead sheath for such cables, a sentiment based largely on the poor showing made by alloy sheaths in a number of instances and the feeling that a softer sheath would be less likely to crystallize. It was only when exhaustive laboratory experiments had shown the great superiority of a proper alloy over pure lead that the final solution was reached.

The following table gives some results of a series of experiments on the ability of different materials to withstand rupture when subjected to continued vibration under stress. In each case the test samples were strips 4 in. long, narrowed for 2 in. in the center to a section measuring $\frac{1}{2}$ in. by $\frac{3}{64}$ in. One end was fastened to a metal tongue pressing lightly against a toothed wheel and the noted weight suspended from the lower end. The tongue was given approximately 108 complete vibrations per second. Where two weights are noted the larger was added to hasten rupture.

VIBRATION STRAIN FOR CABLE SHEATH MATERIALS

Material	Weight suspended	Time of stress
1. Lead Pure	13 lb. 2 oz.	55 m.
2. " "	6 lb.	10 hr. 15 min.
3. Lead 99.5%, tin 0.5%	13 lb. 2 oz.	32 hr.
4. Lead 99.0%, tin 1.0%	*a*—13 lb. 2 oz. *b*—23 lb. 2 oz.	74 hr. with "*a*" and 1 hr. " "*b*"
5. Lead 97.0%, tin 3.0%	*a*—13 lb. 2 oz. *b*—23 lb. 2 oz.	48 hr. with "*a*" and 9 hr. " "*b*"

With the advent of creosoted wooden conduit a great deal of trouble from the chemical corrosion of the sheaths was experienced. In these earlier ducts, wood creosote was the preservative agent employed but owing to the presence of considerable acetic acid, this had a ruinous action on sheath materials. Elaborate experiments at the time proved that while not wholly free from such corrosion, the 3-per cent tin alloy sheath was corroded much less than one of pure lead or with but a small proportion of tin. While improvements in the process of creosoting by the substitution of dead oil of coal tar for wood creosote thereby eliminating the acetic acid, and the advent of vitrified clay ducts, have practically eliminated chemical corrosion from the field of cable trouble, it was one of the factors which at the time led to the adoption of the present standard sheath material. Although an excess of tin renders the alloy too hard and brittle, only the minimum limit needs to be specified, the high price of tin automatically keeping the amount used as small as possible.

Cable specifications. In conclusion, a word might be said about the standard cable specifications to which reference has already been made. These specifications aim primarily to secure a certain standard for the finished product without unduly restricting the manufacturer as to the exact processes he shall employ to attain the desired end. While certain of the mechanical characteristics are incorporated, such as the use of a particular alloy for the sheath, and the employment of paper insulation to the exclusion of other materials, it is on account of experience having shown them to be the best available.

As a result of this aim, the specifications, though brief, have the clauses so drawn as to ensure the equivalent of a process known to be satisfactory. In the matter of brevity the present-day specification is analogous to the earliest specifications, which also aimed at a suitable finished product without specifying particular processes. There is this marked difference however: much of the brevity of the earlier specifications resulted from an insufficient knowledge of the characteristics and possibilities of the materials and processes employed, while the brevity today is the result of a definite knowledge gained from long experience and a more comprehensive conception of the fundamental laws governing the efficient transmission of high-frequency currents, of just what each material will do under varying conditions and just what the limitations of any particular process are.

Between the specifications of the late '80's and those of to-day an era intervened in which it was frequently customary to specify minutely the exact process to be employed and the behavior of the finished cable under widely differing conditions, such, for instance, as the specification of just what the allowable capacity should be at a number of different temperatures. And however much future specification requirements may differ from those of today as regards subject matter, owing to advances in the art, the laws governing the propagation of currents along wires are sufficiently well known to make a recurrence of this type of specification unlikely.

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EVEN HARMONICS IN ALTERNATING-CURRENT CIRCUITS

BY JOHN B. TAYLOR

In the usual presentation and consideration of wave-forms in alternating-current circuits we are so used to the mathematical expressions which omit the second, fourth, sixth, etc. harmonics and so generally assume that these even harmonics can be neglected at the outset, that a short consideration of usual and special conditions, giving rise to even harmonics in alternating-current circuits, seems opportune.

From discussion with many engineers, I find that the following misconceptions are quite popular:

a. There can be no second harmonics in alternating-current circuits, because this would result in a direct-current component in the circuit, obtained without commutator or other rectifying device.

b. Even harmonics cannot be handled by typical transformers, so that should there be any even harmonics at one part of the circuit these will be in some way suppressed or balanced at the first transformation.

c. Wave-forms of electromotive force from commercial generators do not contain even harmonics, hence nothing can give rise to them later in the system.

No explanation is offered as to why these misconceptions should be so common, and a slight endeavor to get at the root of the notions shows that the average text-book on alternating currents, at some point usually near the introduction, states that windings and poles of commercial generators are symmetrical, so that alternate waves will be of the same shape and hence have no even harmonics. Little or no reference to even harmonics is made later in such books.

As a matter of fact, the number of transmission systems at this very moment transmitting, with transformers transforming, and receiving apparatus receiving, alternating currents in which the even harmonics are quite as prominent as the odd and al-

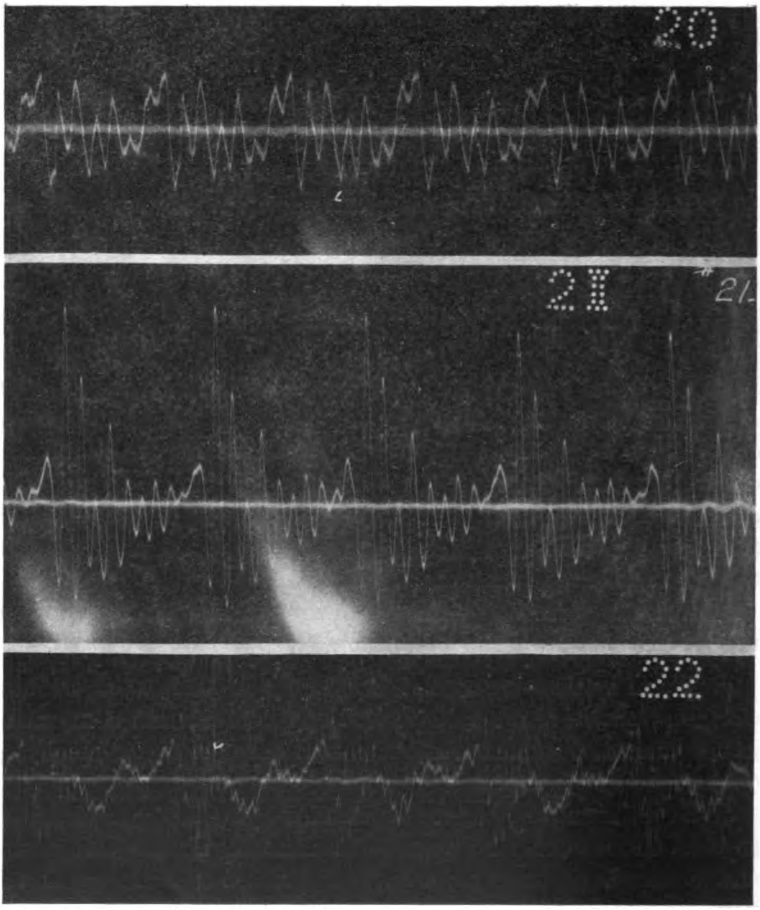

Fig. 1.—Record of telephone currents with sustained vowel sounds in transmitter. Upper curve, *u* (as in rude). Middle curve, *a* (as in far). Lower curve, *i* (as in machine). All pitched at *A* 110; that is, the *A* above 8 foot or cello *C*. J. B. Taylor's voice, April 18, 1907. (Time proceeds from left to right.)

together essential to the proper operation of the system—the number of these systems is so much greater than all the lighting, power, and railway plants added together, as to leave no comparison between the figures. By this, reference is made to the number of telephone conversations being carried on at any one time. The wave-form corresponding to speech is very complex if analyzed in the usual method by Fourier's Series, and the accompanying oscillograph records in Fig. 1, which shows current corresponding to simple sustained vowel sounds, will give an idea of the even, as well as odd, harmonics that telephone lines, transformers and receiving apparatus have to deal with.

There is no difficulty in constructing an alternating-current generator to have a wave-form containing considerable even harmonics, when such are desired. There is also no difficulty in connecting standard generators in series or in parallel for example, a 25-cycle generator and a 50-cycle generator, when the resulting wave-form will have pronounced even harmonics.

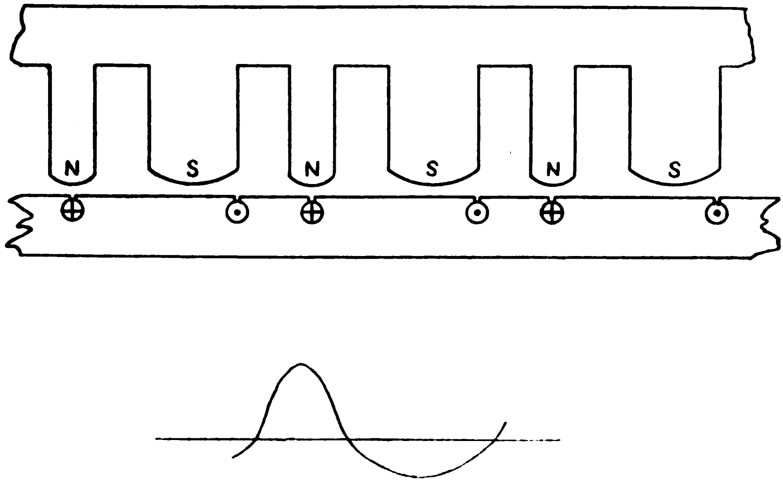

FIG. 2

If an alternating-current generator has a *symmetrical* armature winding and *unsymmetrical* north and south poles, the even harmonics will not appear. If the winding is *unsymmetrical* with the north and south poles *symmetrical*, again the even harmonics will be absent. The combination, however, of an *unsymmetrical* winding with *unsymmetrical* poles, will in general bring out even harmonics. Fig. 2 shows diagrammatically such an alternating-current generator with approximate wave-form due to the special arrangement of winding and the differently shaped north and south poles.

Neglecting the special case of the telephone, of more practical consideration than what has preceded are typical commercial systems in which even harmonics are likely to be introduced and the effect of these harmonics on transformers. The simplest way in which even harmonics may be brought into an alternating-current system is by grounding at more than one point, and these points may be neutral or not. For example, Fig. 3 shows a typical three-phase, high-tension transmission system with transformer neutrals grounded at both ends. Fig. 4 shows the typical single-phase railway with ground at sub-station and also at various cars along the line. A neighboring direct-current traction system causes direct current, in a greater or less amount depending on bonding and other features, to be shunted into the alternating-current system. This flows through the transformer windings giving what I term a " magnetic biased " condition. In other words, there is magnetic flux in the iron of the transformer, apart from excitation derived from alternating-current mains.

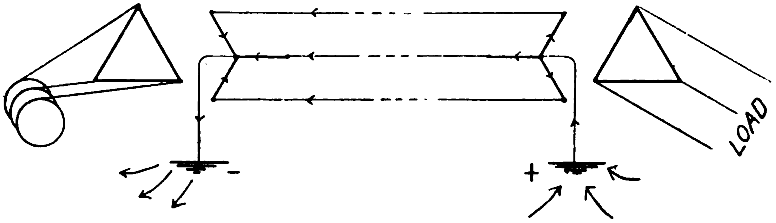

FIG. 3

This shunted or leakage direct current may easily be as much as, or greater than, the exciting current of the transformer, which will give normal or greater magnetic density in the iron, and since many transformers are worked well up toward the saturation point, the iron in the transformer may be nearly saturated before any connection is made with alternating-current supply.

This combination in which transformer iron is initially at a greater magnetic density than is reached in normal alternating-current service, gives a condition which some persons, on superficial consideration, have stated to be equivalent to a heavy overload or short-circuit on the transformer. The argument is, that since the iron is already practically saturated, the normal flux must be added to this saturated condition in order to give the normal counter electromotive force. While such a condition may exist for a very short interval of time when closing the circuit the stable condition is not at all of this nature. The magnetizing current under the conditions described, that is, with direct current in windings of the same order of magnitude as the normal exciting current, does not cause the exciting current to become of the order of a short-circuit current nor even full-load current. This is because the iron, instead of working from the saturated condition as a mean point, works about a mean point not far from zero, and in that portion of a cycle when the flux is in the opposite direction to the initial saturated condition due to direct current, enough extra current from the alternating circuit is supplied practically to neutralize the direct-current ampere-turns. The general effect of this is to increase the exciting current, accompanied by a distortion of the current wave-shape, as shown in the oscillograph record in Fig. 5.

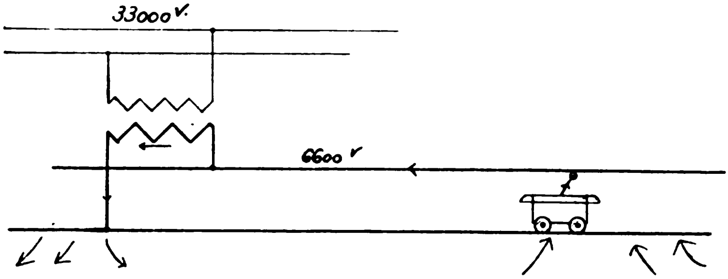

Fig. 4

Roughly, the value of this exciting current, when transformers are magnetically biased, is the value of the normal exciting current added to the direct current. In other words, it may be said that there is a component of the alternating current tending to neutralize the direct-current ampere-turns, and, as another component, the normal exciting current.

If the direct current is in the primary winding and the excitation is from the secondary, or vice versa, the direct current must be multiplied by the ratio of transformation in order to obtain the equivalent direct current for this addition. For example, referring to Fig. 4, the 6600-volt, single-phase trolley wire with sub-station transformer and car as indicated, may have shunted into the winding a current of 5 amperes. The normal exciting current of the sub-station transformer from the 33,000 volt transmission line is, say, 0.5 ampere, but due to the 5 amperes in the secondary winding, the primary exciting current will become $0.5 + \frac{5 \times 6600}{33000} = 1.5$ amperes. There will be some additional losses in transformers carrying direct current, due mainly to increased current density in the winding, and probably a small increase in iron losses due to the unsymmetrical magnetic cycle with maximum flux of one polarity greater than normal.

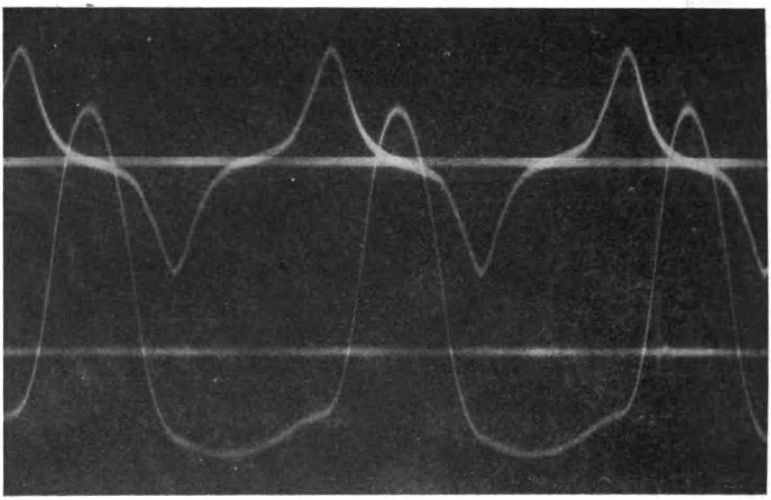

FIG. 5.—Record showing pronounced second harmonic in transformer magnetizing current due to direct current in windings. Upper curve: electromotive force at terminals from 60-cycle generator. Lower curve: exciting current.

The arrangement of apparatus as shown in Fig. 6, gives a convenient way of introducing direct current into a transformer winding without at the same time allowing the direct-current circuit to become a load or short-circuit on the transformer. This test requires two transformers, preferably identical, with primaries connected in parallel, and secondaries (with alternating potential balanced) in series with any convenient source of direct current.

In case it is necessary to make such test on a single transformer, a reactance can be introduced in the direct-current circuit to prevent appreciable alternating current from circulating in the direct-current system, or a low-voltage winding on the transformer can be connected through resistance to a high-voltage, direct-current source, such as a 600-volt railway system. If the voltage of the transformer winding is small compared with the direct voltage, the alternating current flowing into the direct-current system will be negligible.

Another combination of apparatus which may introduce direct current in transformer windings, is a synchronous converter connected for Edison three-wire service, the neutral for the three-wire service being derived from connection with transformer neutrals.

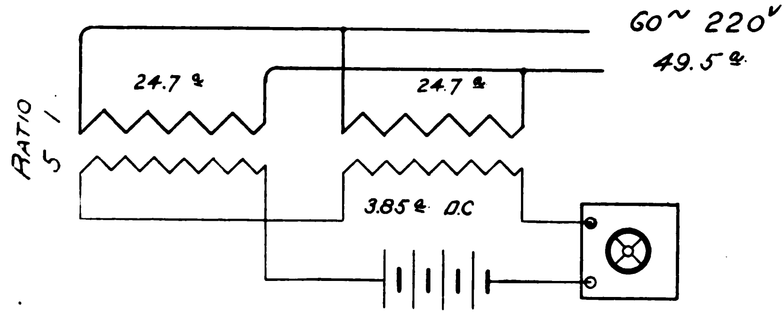

Fig. 6.—Connections for test. 75-kw. transformers. Connected for ratio 5 . 1–1150-230 volts. Excited from 220 volt, 60-cycle circuit. Direct current, 3.85 amperes in 1150-volt winding. Normal exciting current at 220 volts, 60-cycles, -approximately 5 amperes. Calculated exciting current with direct-current magnetization. (5 x 3.85) + 5 = 24.25 amperes—(Observed value was 24.7 amperes.)

With this combination, the difference between the currents on the two sides of the lighting system passes through transformer windings. If the transformers are " diametrically connected " to the converter, this direct current will divide; and if the resistance of transformer and converter connections are symmetrical from the neutral point, this divided direct current will cause no magnetic flux.

However, with the direct-current neutral derived from star-connected transformers, direct current from the neutral does give a biased magnetic condition in the transformer iron with accompanying increase of transformer exciting current and change in wave-shape, as explained above. Since this current divides among three transformers and its magnitude is not great, unless the lighting system is badly unbalanced, little additional transformer heating is likely to be noticed. Star-connected transformers have been so used with converters for a number of years without serious results, as far as I can learn. However, a diametrical connection seems preferable when laying out a new system.

Conclusion. The practical feature of this discussion is that leakage of direct current into transformer windings—unless these currents are of themselves sufficient to cause considerable additional heating in the windings—will not indirectly cause sufficient increase in the exciting current to cause serious overheating or burn-out. I have already proposed the use of counter electromotive force cells, similar to storage-batteries but with plates unformed, in order to check leakage direct currents, but have not yet seen a case where the magnitude of these currents was sufficient to warrant such additional and undesirable complication of apparatus.

A paper to be presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 28, 1909.

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MULTISPEED INDUCTION MOTORS

BY H. G. REIST AND H. MAXWELL

The induction motor, as generally used, has a speed which varies slightly with the load but which is usually spoken of as being constant. For work where variable speed is required, a motor with collector rings is used, the speed variation being produced by varying the amount of resistance inserted in the secondary circuit. Such a motor is wasteful of power whenever resistance is used, and the speed varies greatly with the load when much reduction in speed is required.

It sometimes happens that the work is of such a character that two or three speeds will be satisfactory for the operation of the machinery. For such conditions multispeed motors can frequently be used. In these motors the different synchronous speeds are produced by changing the number of poles in the magnetic circuit. Each of these speeds is fixed if no resistance is used in the secondary circuit, so that a change in load will produce only a very slight variation in speed, and the motor will operate efficiently at each speed. With multispeed motors, as with ordinary motors, secondary resistance may be used to vary the speed below each of the synchronous speeds. In this way the complete variation of the speed over a wide range may be obtained more efficiently than with a simple collector-ring motor, but the motor and the control apparatus may be so complicated that the saving of power is not warranted.

A change in the number of poles may be produced in any one of the following ways:

a. By the use of single magnetic and electric circuits, changing the number of poles by re-grouping the coils.

b. By the use of a single magnetic circuit and independent electric circuits.

c. By means of separate magnetic and electric circuits.

The selection and design of the multispeed motor is affected principally by the number of speeds required, the ratio of the desired speeds, and the ratio of the maximum outputs at the different speeds.

a. *Single magnetic and electric circuit.* This type has probably been used more extensively than any other type of multispeed induction motor, due to its economical use of material all of which is active at all speeds. Except in a special case, a disadvantage of this type of motor is the large number of leads which must be brought out of the winding, and the complicated switching apparatus needed for interconnecting them.

For any ratio of two speeds other than 2 : 1, the ordinary three-phase winding requires 33 leads. For a two-phase winding or a three-phase teaser winding, the winding may be arranged with 16 leads. If more than two speeds are desired, the number of leads will be greatly increased and in general will approximate the number made by bringing out the leads of each coil, thus requiring nearly twice as many leads as there are coils in the machine. In this form of motor the same coils are used for the different arrangements of poles, the relative pitch of the winding depending on the number of poles. Since the economy of a winding rapidly decreases when the pitch of its coil is less than one-half, it is disadvantageous to build motors of this type having a greater change of speed than 2 : 1. On account of the large number of leads required, it is not practicable to use this type of winding on the rotors of induction motors, except with a ratio of 2 : 1 speed, with which arrangement only six collector rings are required. With all other speed-ratios the number of collector rings would become prohibitive, so for these motors a squirrel-cage winding is generally used on the secondary.

When the speed-ratio is 2 : 1, this type of motor can be applied advantageously, and a great many have been built and have been in successful operation for several years. A motor wound in this way is practicable for either a wound type of rotor, since it requires only six collector rings, or for a squirrel-cage rotor, which is more generally used.

There are a number of different methods that may be used in connecting the windings of such motors, the selection of the connection in any case depending on the relative maximum outputs required at the two speeds. The connection which has frequently been used where the material is worked to the best advantage, has a half-speed rating of from 60 per cent to 70 per cent of full-speed rating. The following table gives several different connections that may be used, with the approximate relative outputs of the different connections. The third combination shown on this table is the one generally used, as it best suits the average conditions of a load which requires constant torque at the two speeds; that is, when the output of the motor is proportional to the speed.

Speed	Connection	Approximate maximum output
(1) 100	2-Circuit Delta	100
50	Y-delta	11
(2) 100	2-circuit Y	100
50	1 " Y	22
(3) 100	2 " Y	100
50	1 " Delta	66
(4) 100	1 " Delta	100
50	2 " Y	117
(5) 100	1 " Y	100
50	2 " Y	350
(6) 100	Y Delta	100
50	2 Circuit Delta	700

These values are approximate and will vary slightly with the ratio of the reactance to the resistance and also with the ratio of the coil-end to the slot part of the reactance leakage.

From an inspection of the table it will be seen that there is a wide range of maximum torque from a little over 10 per cent for the half-speed connection, to about seven times that of the full-speed connection. These various combinations are often valuable in extraordinary cases to maintain a good power-factor and efficiency at the desired loads. In most of these combinations the material is not worked to equal advantage at both speeds.

b. Motors with a single magnetic circuit and independent electric circuits. This type of multispeed motor has the advantage of using the same magnetic circuit at all speeds, and therefore requires only one stator and rotor structure, the same as an ordinary motor. These motors, having independent windings, have three leads for each speed in the stator for three-phase motors and four for two-phase motors.

The slots in this type of motor are usually made large enough to contain the two or more windings used in making the several windings for the different speeds. It is theoretically possible to obtain a number of synchronous speeds, but it is usually impracticable to use more than two windings. The relative maximum outputs are independent of each other, but to work the magnetic material to advantage it should be approximately proportional to the speed. The motors of this type have to be built large for their output in order to allow space for the increased amount of copper and insulation. The space occupied by insulation becomes excessive on high-voltage motors so that this type is applicable chiefly to low-voltage windings. It is possible in this form of motor to utilize one or more of the windings mentioned in type (*a*), thus increasing the possible number of speeds. Since there are two or more distinct windings, the construction is more complicated and the motors are somewhat more difficult to repair than when only one winding is used.

c. Separate magnetic and electric circuits. The concatenated motor is the only motor of this type in general use. This consists of two motors, the rotors of which are mounted on the same shaft arranged so that the secondary of the first motor is directly connected to the primary of the second motor. The two motors may have the same number of poles, but usually the number of poles is different. The effect produced by the second motor is that of adding to or subtracting its poles from the first motor. It will be seen that if the two motors have a different number of poles, there will be four synchronous speeds, two for the motors independently and two for the combination. If the speed corresponding to the difference in the number of poles is higher than the synchronous speed of the first motor, the set will not accelerate by itself to this speed; and although there might be ways of accelerating to this speed, the switching devices will be complicated so that from a practical standpoint this combination is not generally considered.

By using in concatenation two of the half-speed motors mentioned in class (*a*), the number of speed combinations is very large, and the number of leads and switching of the electric circuits, while complicated, may be warranted in some cases. If, for instance, we take a 4–8 pole and a 6–12-pole motor, we can obtain combinations to give motors having speeds equivalent to every possible number of poles from 4 to 20, except 18.

The ratio of speed of the two motors is limited by the necessity of changing the poles of each motor, two at a time. A further limitation is the centrifugal stresses in the larger motor at high speeds. If the individual motors have the same synchronous speed and can be run in multiple at the high speed, the ratio of the maximum output of the high speed to the low speed is about 4 : 1. If the load requires this ratio of work with the different speeds, the material in the motor is worked to the best advantage.

The two conditions—of having a load as desired in the foregoing and having speeds with ratio of 2 : 1—rarely exist, so in general the material cannot be economically used in concatenated motors. The ratio of the outputs mentioned is usually unfavorable, since in general the output required at the lower speed is more than one-quarter that required at the higher speed. There are some classes of work, however, such as the driving of blowers, where approximately this load-ratio may exist.

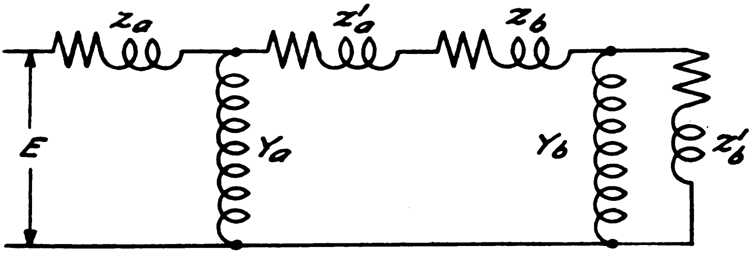

Fig. 1

On account of the large variation in output at the two speeds, the concatenated motors generally use material at the high speed to a very great disadvantage, so that such motors are usually large and expensive for the work to be done. The most favorable condition for the use of the concatenated motor is when the various speeds required are close together. In such a case the two motors would be very different in size and the large motor would be used for the highest speed; for example, if the large motor had 16 poles and the small one had 4, speeds corresponding to 12, 16, and 20 poles could be obtained.

Another disadvantage of the concatenated motor is its low power-factor. This is inherently low, even at the highest speed, owing to the fact that the normal load carried on the individual motors is seldom as large in proportion as the necessary maximum output of these motors in order to obtain sufficient output when the motors are used in combination; in other words, the higher-speed motors will give a poor power-factor because they are underloaded.

To explain the characteristics of the concatenated motors

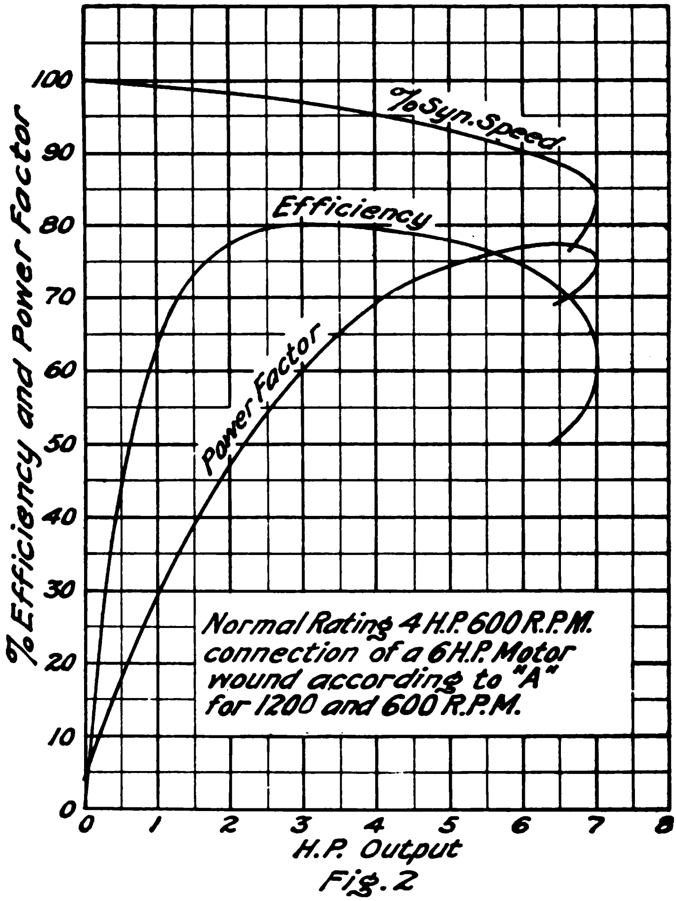

Fig. 2

more clearly, attention is called to Fig. 1* which represents circuits equivalently arranged;

In this diagram Z_a and Z_b represent the impedance of the primary circuit of the two motors A and B, and Z_a', Z_b' their secondary impedance, while Y_a and Y_b are their exciting admittances. The resistance component of the impedance is here understood to be corrected for each circuit according to the frequency of that circuit, so that all terms are given as their equivalent value for full frequency.

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* For explanation of Fig. 1 see E. Arnold, "Die Wechselstromtechnik" Vol. 5, Part 1, Fig. 265.

The load current travels around through Z_a, Z_a', Z_b, Z_b', in series, while the magnetizing circuits Y_a and Y_b are across the line with full voltage impressed upon them, except for the voltage drop in the primary circuit in the winding of A for Y_a, and the additional drop of the secondary of A and the primary of B for Y_b. Since these voltage-drops are small at normal load, we can neglect them and say that the impedances of both motors are added, and, likewise, that the magnetizing currents of the two are added.

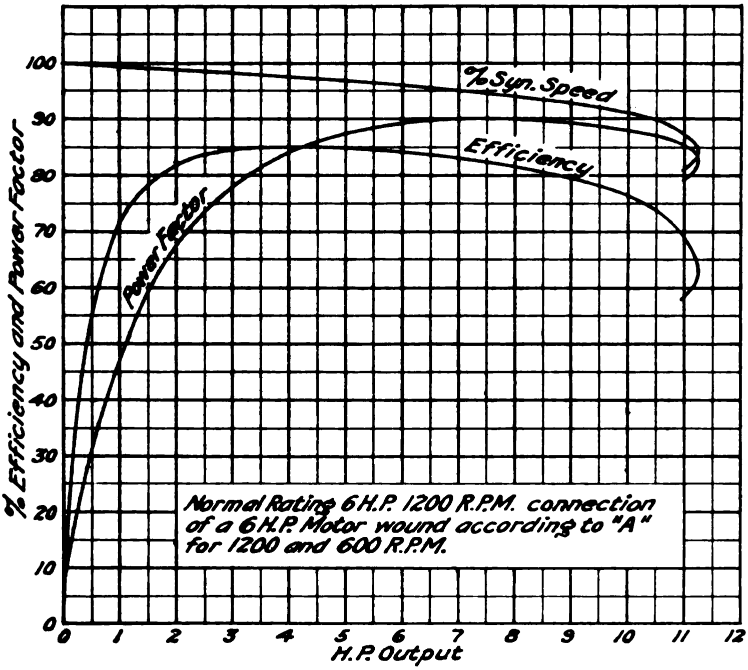

Fig. 3

The maximum output of a motor is inversely proportional to its impedance at a given frequency and voltage, so that if the two single motors have equal impedance, the maximum output of the concatenated couple is approximately one-half the maximum output of one motor alone, and its magnetizing current is approximately twice that of one motor—hence its inherent low power-factor in concatenation.

Two curves from actual tests of motors are reproduced to illustrate the points that we have tried to bring out regarding the various characteristics of two of the types of motors mentioned. The curves in Figs. 2 and 3 show the characteristics of a motor of type (*a*) wound for full speed and half speed according to No. 3 connection of the table given. The curves in Fig. 4 show the characteristics of two motors of equal size run in concatenation. Fig. 5 shows the characteristics of one of the motors in Fig. 4 run at the high-speed connection, the other motor being idle. If both motors were run in multiple at the high speed, the output would be twice as great as indicated in Fig. 5.

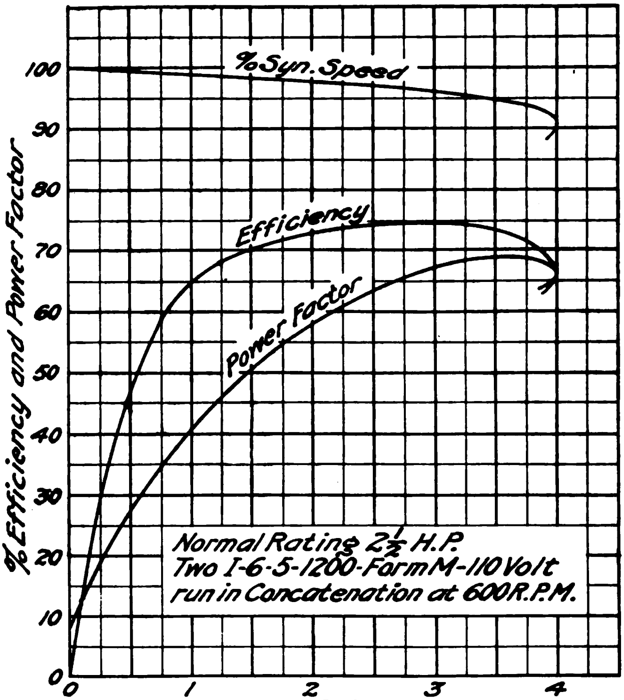

Fig. 4

As a suggestion in the selection of the best type for various conditions, we have drawn up the following conclusions which must, however, be interpreted very broadly as there are many modifying circumstances.

1. For two speeds having a ratio of 2 : 1, use motor type (*a*).

2. For two speeds having other ratios than 2 : 1, use motor type (*b*), except when the winding and insulation require too much space.

3. When three speeds are required, two having a ratio of 2 : 1, the other being intermediate, type (*b*) may be used with one winding connected as in (*a*).

4. If four speeds are necessary, one speed being one-half of the highest speed, and the lowest speed one-half of the next highest speed, type (*b*) may be used, with each winding such as is used in type (*a*).

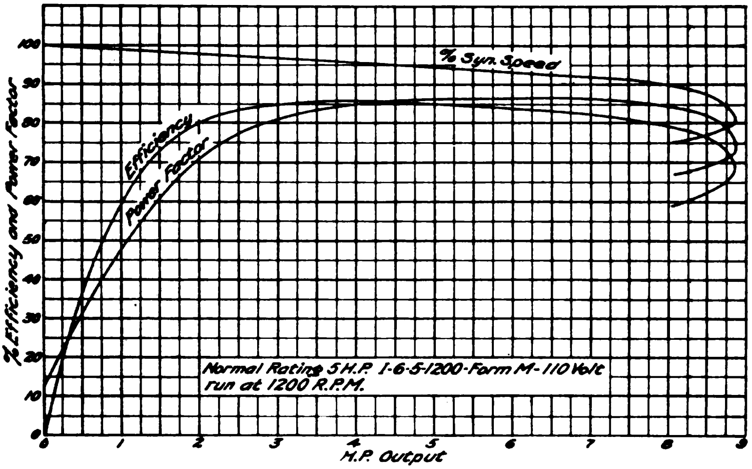

Fig. 5

5. Use type (*c*) concatenated motors, when two or more speeds close together are required.

6. Use concatenated motors when polar windings on the rotor are necessary with more than two speeds, or if the two speeds differ from 2 : 1.

7. Use concatenated motors for high-voltage machines except when type (*a*) can be used.

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ELECTRICAL MEASUREMENTS ON CIRCUITS REQUIRING CURRENT AND POTENTIAL TRANSFORMERS

BY L. T. ROBINSON

Modern requirements make it necessary to measure alternating current, volts, and watts on circuits where the magnitude of these quantities and the safety of the operator require that some means be provided so that the instruments used are not directly connected to the circuit. In certain special measurements it may be found accurate and convenient to use resistances to multiply the indications of the instrument, these resistances being used as shunts to the current coil or in the potential coils of voltmeters or wattmeters.

In a great majority of cases the most convenient arrangement is that of employing current and potential transformers. It is, therefore, necessary to be able to determine with exactness the ratio of these transformers under various conditions of frequency, voltage etc., to which they may be subjected in use. In connection with the measurement of watts it is also necessary to consider the phase displacement between the primary and the secondary current or voltage used on the transformers.

It is the purpose of the present paper to discuss, briefly, from a practical point of view, the causes which make certain corrections necessary either in the manufacture of the transformer or in their use; the most suitable methods for determining the variations in transformer ratio and phase-angle; the general order of magnitude of these errors or corrections and the most convenient way in which the known values can be made use of to correct the instrument readings which have been obtained. Before considering the question of transformers it may be well to discuss briefly certain points which relate to the instruments alone. In measuring amperes on alternating-current circuits, if ammeters are provided, having no correction factor due to frequency or wave-form, and which, therefore, measure directly the effective value of the current flowing, they may be tested on direct current. If without hysteresis as well, they may be used on alternating-current circuits without error.

Most ammeters which have been found useful for commercial purposes are not entirely free from one or more of these errors, and to obtain the most accurate results which they are capable of giving, they must be tested on an alternating-current circuit of the same order of frequency as that on which they are to be used. In some instruments the range of frequency, wave-form etc. over which they may safely be employed, is greater than that found in any usual application, while others may be applicable to accurate measurements only within much closer limitations. However, it may be said that ammeters are readily obtainable both for switchboard and for portable use, the errors, due to any conditions under which the ammeters may be used, being so small that they may be neglected. If these meters are once calibrated on an alternating-current circuit of, say, 60 cycles, they may be used on any commercial frequency or wave-form without sensible error.

It is in general true that ammeters can be made having only a limited current-carrying capacity; and for measurements of current beyond this range, as well as for use on circuits where protection against high voltage is required, some arrangements are neccesary for causing a known part of the current to pass through the ammeter. The most satisfactory arrangement is the current transformer. For use with ammeters it is necessary to know the relation between the primary and the secondary currents under various conditions in which ammeters and other devices, having a different total resistance and reactance, are included in the secondary of the transformer.

In measuring volts somewhat similar considerations apply, with slight modifications, although in this case potential transformers of known ratio must be used.

In measuring watts, either current or potential transformers or both may be required. In addition to errors similar to those found in ammeters and voltmeters, but usually much less, in fact usually too small to be considered at all, wattmeters have an inherent error appearing as an effect equivalent to a displacement between the current in the moving coil—potential circuit—

and the electromotive force impressed upon the circuit to be tested.

It has been customary in theoretical discussions to compute this angle from the resistance and inductance of the potential circuit, but there are various other actions within a wattmeter that make it necessary to determine, by suitable means, this equivalent angle as it exists in the instrument. The discussion of the magnitude of this quantity, and of the most suitable means for determining it, is not the purpose of the present paper. It will be assumed that such an equivalent angle has either been determined or is too small to appreciably effect the results under the conditions in which the instrument is to be used. This angle is different for different frequencies and is also affected in somewhat imperfect instruments, due to other causes. Therefore, in speaking of this angle it must not be considered that it can be assigned a fixed value in all cases, but that a value for the angle is chosen which is suitable for the immediate conditions under which the instrument is used.

In using current or potential transformers with a wattmeter it is well known that the phase-angle between the primary and the secondary of the transformer must be taken into account, if the most accurate results are to be obtained. It may also be said that usually the effect of these transformer angles, especially when current transformers are used, is to cause errors in the indications of the wattmeters much geater than those caused by the equivalent angle of the instrument alone. Before proceeding to the consideration of ratio and phase-angle in current and potential transformers it is well to discuss the relation that these various angles have to the results obtained when wattmeters are used. The ratios of any transformers used have, of course, the same effect on a wattmeter as on an ammeter and voltmeter.

Before discussing the means which may be employed to determine the ratio and phase-angle in current and potential transformers it may be well to state briefly the effect which these angles will have on the indications of a wattmeter with which they are used. We will call the equivalent angle of phase displacement in the wattmeter α, the angle of phase displacement in the current transformer β, and the same quantity in the potential transformer γ. In an instrument in which the eddy currents have been quite completely eliminated, the angle represents a lag in the potential circuit, and when so existing will be given the positive sign, or $+\alpha$. In some instruments, however, due to causes which have been briefly referred to, this correction appears as an effect equivalent to leading current, in the potential circuit, in which case the equivalent correction angle will be written as $-\alpha$.

Current transformers, as usually made, when carrying an instrument load give leading current in the secondary circuit. The effect of this is the same on the connected wattmeter as lagging current in its potential circuit, and, therefore, leading current in the secondary of the current transformer will be written $+\beta$.

Potential transformers, as usually made, give leading potential in the secondary, which affects the instrument in the same way as some cause within the instrument, which would make the current lead in the potential circuit; therefore, leading potential in the potential transformer will be written $-\gamma$.

It is useful to remember that in all cases correction angles tending to decrease the phase displacement between the current and the potential circuits in the instrument, are to be considered as positive, and those tending to increase the phase displacement as negative; so that if the sum of the correction angles is positive, the wattmeter reading will, with lagging current, be greater than the true watts.

We will consider lagging current in the main circuit to be represented by a positive angle θ, and leading current by the same symbol with a negative sign $-\theta$. The reading on any wattmeter, divided by the volt-amperes, is equal to the apparent power-factor. Using $\cos\theta_2$ to represent the apparent power-factor of the circuit we can write

$$\text{Cos}\,\theta_2 = \frac{\text{wattmeter reading}}{\text{volt-amperes}} = \text{apparent power-factor} =$$

$$\cos(\theta \pm \alpha \pm \beta \pm \gamma) \text{ or } \cos\theta = \cos(\theta_2 \mp \alpha \mp \beta \mp \gamma)$$

where α, β, γ are the correction angles above referred to, which have been added with their proper sign to the angle of lag θ_2. If the angle θ_2 is leading it may be considered as a negative angle so that negative correction angles added to it will increase the total angle, or vice versa.

The ratio of the true power-factor to the apparent power-factor is naturally the correction to be applied to the indications of the instrument, as the instrument reading is due to the apparent power-factor. Therefore, the following relation holds.

$$\text{wattmeter reading} \times \frac{\cos\theta}{\cos\theta_2}$$

$$= \text{wattmeter reading} \times \frac{\text{true power-factor}}{\text{apparent power-factor}} = \text{true watts}$$

In some instances, when using wattmeters of small capacity it is necessary to correct the instrument reading for the losses in the instruments used. Usually the correct way to do this is to connect the voltmeter and the potential winding of the wattmeter in such a way that the energy consumed in them is measured by the wattmeter, as a part of the total watts. Sometimes this correction amounts to a considerable part of the total reading of the wattmeter. The instrument reading is then made up of two parts, one of which, the loss in the potential circuits of the instruments, is nearly or quite non-inductive, while the other may be inductive, and therefore require correction. It is still correct to use the total watts determined in this way in obtaining the apparent power-factor, and after the correction has been applied the measured or computed losses in the potential circuits may be deducted.

Perhaps the process can be best illustrated by examples. In the first case the correction is applied to an instrument used alone whose equivalent phase-angle is known, and in the second case current and potential transformers are used. In the first case also the watts lost in the potential circuit of the instrument itself have been subtracted, and in the second case this quantity is too small to be considered.

Example 1,

lagging load, 60 cycles, $P3$ wattmeter, volts 100, amperes 10.
resistance of wattmeter potential circuit 2500 ohms.
resistance of voltmeter potential circuit 2200 ohms.

$$\text{Watts consumed in instruments } \frac{100^2}{2500} + \frac{100^2}{2200} = 8.5 \text{ watts.}$$

Watts read corrected for scale error $= W = 100$
$\alpha = +3$ minutes

$$\frac{W}{V\ A} = \cos\theta_2 = \frac{100}{1000} = 0.1$$

Therefore, θ_2 = 84 degrees 16 min. (cos = 0.0999) and
$\theta = \theta_2 + \alpha$ = 84 degrees 19 min. (cos = 0.099).

True watts = $\frac{100 \times 0.099}{0.0999}$ = 99. From this we subtract 8.5, the instrument losses, leaving 90.5, the required value.

Using the same values as above with leading load,

$\frac{W}{V\,A} = \cos\theta_2 = \frac{100}{1000} = 0.1$, therefore, $\theta_2 = -84$ degrees 16 min. (cos 0.0999)
and $\theta = -\theta_2 + \alpha = -(\theta_2 - \alpha) = -84$ degrees 13 min. (cos = 0.1008

true watts = $\frac{100 \times 0.1008}{0.0999}$ = 101 nearly.

Subtracting instrument losses, 8.5 watts, we have 92.5 watts, the required value.

Example 2,

lagging load, 25 cycles,
current transformer, ratio 39.64:1, (99.1 ×40 from curve)
potential transformer, ratio 19.94:1,
volts 104.4 ×19.94 = 2082.
amperes 2.5 ×39.64 = 99.1
V A 206,360. Wattmeter reading 53.
apparent watts = 53 ×39.64 ×19.94. =0.41893.

$$\text{Cos}\ \theta_2 = \frac{41{,}893}{206{,}360} \doteq 0.20301,$$

therefore θ_2 = 78 degrees 17 min. 20 sec.

α at 25 cycles is negligible.

$\beta = +55$ min.; $\gamma = -38$ min.; $\theta \doteq 78$ degrees 17 min. 20 sec. +55 min. − 38 min. or 78 degrees 34 min. 20 sec.

Cos θ = 0.1981. Then the true watts $= 41893 \times \frac{0.1981}{0.203} = 40880.$

As in the first example, the instrument and potential transformer losses are to be subtracted, if appreciable and if the connection used requires it. In this example they are too small to be considered. If the load is leading, the sign of θ_2 is to be changed as in example 1.

To be useful in practical work some arrangement must be provided, whereby the necessary computations may be quickly made, and for this purpose Table I and Table II have been

TABLE I

$\frac{\cos\theta}{\cos\theta_2}$ LAGGING LOAD WITH $(\alpha+\beta+\gamma)$ POSITIVE

LEADING LOAD WITH $(\alpha+\beta+\gamma)$ NEGATIVE

Power factor $\cos\theta_2$

$\alpha+\beta+\gamma$	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	0.9855	0.9904	0.9928	0.9943	0.9953	0.9966	0.9974	0.9980	0.9985	0.9989	0.9993
10′	0.9710	0.9808	0.9857	0.9887	0.9907	0.9933	0.9949	0.9961	0.9970	0.9978	0.9985
15′	0.9565	0.9712	0.9786	0.9831	0.9860	0.9899	0.9924	0.9941	0.9955	0.9967	0.9978
20′	0.9420	0.9616	0.9714	0.9774	0.9814	0.9866	0.9898	0.9922	0.9940	0.9956	0.9971
25′	0.9276	0.9520	0.9643	0.9718	0.9768	0.9832	0.9873	0.9902	0.9925	0.9945	0.9964
30′	0.9131	0.9424	0.9571	0.9661	0.9722	0.9799	0.9848	0.9883	0.9910	0.9934	0.9956
40′	0.8841	0.9232	0.9429	0.9548	0.9629	0.9732	0.9797	0.9844	0.9880	0.9912	0.9942
50′	0.8552	0.9040	0.9286	0.9436	0.9537	0.9665	0.9747	0.9805	0.9850	0.9890	0.9928
1°	0.8262	0.8848	0.9143	0.9323	0.9444	0.9598	0.9696	0.9766	0.9820	0.9868	0.9914
10′	0.7971	0.8655	0.8999	0.9210	0.9350	0.9530	0.9645	0.9726	0.9789	0.9845	0.9899
20′	0.7681	0.8463	0.8857	0.9097	0.9257	0.9463	0.9594	0.9687	0.9759	0.9822	0.9884
30′	0.7391	0.8271	0.8713	0.8984	0.9164	0.9396	0.9543	0.9647	0.9729	0.9800	0.9869
40′	0.7101	0.8079	0.8570	0.8872	0.9071	0.9329	0.9491	0.9608	0.9699	0.9777	0.9854
50′	0.6811	0.7887	0.8427	0.8759	0.8978	0.9261	0.9440	0.9568	0.9668	0.9755	0.9839
2°	0.6521	0.7695	0.8284	0.8646	0.8885	0.9194	0.9389	0.9529	0.9638	0.9732	0.9824
10′	0.6230	0.7502	0.8140	0.8531	0.8791	0.9126	0.9337	0.9488	0.9607	0.9709	0.9808
20′	0.5940	0.7309	0.7996	0.8417	0.8697	0.9058	0.9286	0.9448	0.9576	0.9686	0.9793
30′	0.5649	0.7116	0.7853	0.8303	0.8604	0.8990	0.9234	0.9408	0.9545	0.9663	0.9778
40′	0.5359	0.6924	0.7709	0.8189	0.8510	0.8922	0.9183	0.9368	0.9514	0.9640	0.9763
50′	0.5068	0.6731	0.7566	0.8074	0.8417	0.8855	0.9131	0.9328	0.9483	0.9617	0.9748
3°	0.4778	0.6538	0.7422	0.7960	0.8323	0.8787	0.9080	0.9288	0.9452	0.9594	0.9733
10′	0.4487	0.6343	0.7277	0.7845	0.8228	0.8718	0.9028	0.9247	0.9420	0.9570	0.9717
20′	0.4196	0.6148	0.7133	0.7731	0.8134	0.8650	0.8976	0.9207	0.9389	0.9547	0.9701
30′	0.3906	0.5953	0.6989	0.7617	0.8040	0.8582	0.8924	0.9166	0.9358	0.9523	0.9685
40′	0.3615	0.5759	0.6845	0.7503	0.7946	0.8514	0.8871	0.9126	0.9327	0.9500	0.9670
50′	0.3325	0.5564	0.6701	0.7388	0.7852	0.8445	0.8819	0.9085	0.9295	0.9476	0.9654
4°	0.3034	0.5369	0.6557	0.7274	0.7758	0.8377	0.8767	0.9045	0.9264	0.9453	0.9638
10′	0.2743	0.5177	0.6412	0.7159	0.7663	0.8308	0.8714	0.9004	0.9232	0.9428	0.9621
20′	0.2452	0.4985	0.6268	0.7045	0.7569	0.8239	0.8662	0.8963	0.9200	0.9404	0.9605
30′	0.2161	0.4793	0.6124	0.6930	0.7474	0.8171	0.8609	0.8922	0.9168	0.9380	0.9590
40′	0.1871	0.4602	0.5980	0.6816	0.7380	0.8102	0.8557	0.8881	0.9136	0.9356	0.9573
50′	0.1580	0.4410	0.5836	0.6701	0.7285	0.8034	0.8504	0.8841	0.9104	0.9332	0.9557
5°	0.1289	0.4218	0.5692	0.6587	0.7191	0.7965	0.8452	0.8800	0.9072	0.9308	0.9540
10′	0.0998	0.4026	0.5548	0.6472	0.7096	0.7896	0.8399	0.8759	0.9040	0.9284	0.9524
20′	0.0707	0.3834	0.5404	0.6358	0.7002	0.7828	0.8347	0.8718	0.1008	0.9260	0.9507

TABLE II

$\frac{\cos\theta}{\cos\theta_2}$ LAGGING LOAD WITH $(\alpha+\beta+\gamma)$ NEGATIVE

LEADING LOAD WITH $(\alpha+\beta+\gamma)$ POSITIVE

Power factor $\cos\theta_2$

$\alpha+\beta+\gamma$	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	1.0145	1.0096	1.0071	1.0057	1.0046	1.0033	1.0025	1.0020	1.0015	1.0011	1.0070
10′	1.0289	1.0192	1.0142	1.0113	1.0092	1.0066	1.0050	1.0039	1.0029	1.0022	1.0014
15′	1.0434	1.0288	1.0213	1.0170	1.0138	1.0099	1.0075	1.0059	1.0044	1.0033	1.0021
20′	1.0578	1.0383	1.0284	1.0225	1.0185	1.0133	1.0100	1.0077	1.0059	1.0043	1.0028
25′	1.0723	1.0479	1.0355	1.0282	1.0231	1.0166	1.0125	1.0097	1.0074	1.0054	1.0035
30′	1.0867	1.0575	1.0426	1.0338	1.0277	1.0199	1.0150	1.0116	1.0088	1.0065	1.0041
40′	1.1156	1.0766	1.0568	1.0450	1.0369	1.0265	1.0200	1.0154	1.0117	1.0086	1.0055
50′	1.1445	1.0958	1.0711	1.0563	1.0462	1.0332	1.0250	1.0193	1.0147	1.0108	1.0069
1°	1.1734	1.1150	1.0853	1.0675	1.0554	1.0398	1.0300	1.0231	1.0176	1.0129	1.0083
10′	1.2023	1.1342	1.0995	1.0787	1.0646	1.0464	1.0350	1.0269	1.0205	1.0150	1.0096
20′	1.2311	1.1533	1.1136	1.0899	1.0737	1.0530	1.0399	1.0307	1.0234	1.0171	0.0110
30′	1.2600	1.1725	1.1278	1.1010	1.0829	1.0595	1.0449	1.0345	1.0262	1.0192	1.0123
40′	1.2888	1.1916	1.1419	1.1122	1.0920	1.0661	1.0498	1.0383	1.0291	1.0213	1.0136
50′	1.3177	1.2108	1.1561	1.1234	1.1012	1.0727	1.0548	1.0421	1.0320	1.0235	1.0150
2°	1.3466	1.2300	1.1703	1.1346	1.1104	1.0793	1.0598	1.0459	1.0349	1.0256	1.0163
10′	1.3754	1.2492	1.1844	1.1462	1.1195	1.0858	1.0647	1.0497	1.0377	1.0277	1.0176
20′	1.4042	1.2683	1.1985	1.1578	1.1286	1.0924	1.0696	1.0534	1.0406	1.0297	1.0189
30′	1.4329	1.2875	1.2126	1.1693	1.1377	1.0989	1.0745	1.0572	1.0435	1.0318	1.0201
40′	1.4617	1.3066	1.2267	1.1809	1.1468	1.1054	1.0794	1.0609	1.0463	1.0338	1.0214
50′	1.4905	1.3258	1.2409	1.1925	1.1560	1.1120	1.0844	1.0647	1.0492	1.0359	1.0227
3°	1.5193	1.3449	1.2550	1.2041	1.1651	1.1185	1.0893	1.0684	1.0520	1.0379	1.0240
10′	1.5480	1.3637	1.2690	1.2147	1.1742	1.1250	1.0942	1.0721	1.0548	1.0399	1.0252
20′	1.5769	1.3824	1.2831	1.2253	1.1832	1.1315	1.0990	1.0758	1.0576	1.0419	1.0264
30′	1.6056	1.4012	1.2971	1.2359	1.1923	1.1379	1.1039	1.0795	1.0603	1.0438	1.0276
40′	1.6344	1.4199	1.3111	1.2465	1.2013	1.1444	1.1087	1.0832	1.0631	1.0458	1.0288
50′	1.6632	1.4387	1.3252	1.2572	1.2104	1.1509	1.1135	1.0869	1.0660	1.0478	1.0300
4°	1.6920	1.4575	1.3392	1.2678	1.2194	1.1574	1.1184	1.1096	1.0687	1.0498	1.0313
10′	1.7206	1.4764	1.3532	1.2788	1.2284	1.1638	1.1232	1.0942	1.0714	1.0518	1.0325
20′	1.7491	1.4952	1.3672	1.2898	1.2374	1.1703	1.1280	1.0979	1.0742	1.0537	1.0337
30′	1.7777	1.5141	1.3811	1.3007	1.2463	1.1767	1.1328	1.1015	1.0769	1.0557	1.0348
40′	1.8062	1.5329	1.3951	0.3117	1.2553	1.1831	1.1376	1.1051	1.0796	1.0576	1.0360
50′	1.8348	0.5518	1.4091	1.3227	1.2643	1.1896	1.1424	1.1088	1.0824	1.0596	1.0372
5°	1.8634	1.5707	1.4231	1.3337	1.2733	1.1960	1.1472	1.1124	1.0851	1.0616	1.0384
10′	1.8920	1.5896	1.4371	1.3447	1.2823	1.2024	1.1520	1.1160	1.0878	1.0636	1.0306
20′	1.9205	1.6084	1.4511	1.3557	1.2913	1.2089	1.1568	1.1196	1.0906	1.0655	1.0408

prepared. With the aid of these tables, knowing cos θ_2 or the apparent power-factor and the angles α, β, γ, the correction factor $\frac{\cos\theta}{\cos\theta_2}$ can be obtained at once.

Table I gives the multipliers for use when $\alpha\pm\beta\pm\gamma$ has various values from 5 min. to 5 degrees 20 min., and when the power-factor varies between the 0.1 and 0.9. Any power-factor above 0.9 may be corrected for by interpolating between the 0.9 value and unity for the required angle. The correction at unity power-factor, for small angles, is too small to be usually considered.

Table I is to be used when the load under test is lagging and when the sum of the correction angles is positive. It is also used for leading load when the sum of the correction angles is negative.

Table II, having the same range as Table I, is to be used for leading load when the sum of the correction angles is positive and for lagging load when the sum of these angles is negative. In the cases where Table I is to be used, the wattmeter reads too high and the correction factors are less than unity, while under the conditions referred to in connection with Table II, the instrument reading is too small and the multiplier must be greater than unity.

Having discussed the reasons why the phase-angle and ratios of the instrument transformers must be known, and what seems to be a convenient way in which the known corrections may be applied, we can, by referring to the table, easily see within what limits of accuracy and power-factor the correction for phase-angle may be neglected, and obtain a very good general idea of the effect of varying the power-factor of the circuit when any combined phase-angle is assumed.

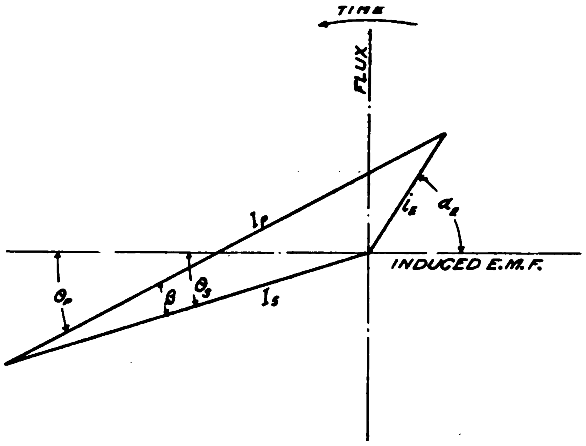
In order to keep the error due to phase-angle within 1 per cent, if the sum of the correction angles is 30 minutes, correction must be applied after the power-factor becomes lower than 0.7. At power-factor 0.5, the error due to this cause would amount to about 1.5 per cent and at power-factor 0.1 to very nearly 9 per cent. To keep within the same 1 per cent limit, as low as power-factor 0.1, the sum of the correction angles must be under 5 minutes. It can also be seen that, within the limits that such corrections would ordinarily be useful, the multiplier to be used is very nearly proportional to the correction angle. The correction angle has no appreciable effect at unity power-factor up to the point where the angle exceeds, by a considerable amount, any magnitude which would usually be met with in practice. The tables have been extended to well beyond such limits.

Where the algebraic sum of the correction angles is greater than 90 degrees minus θ, the multipliers are not given, as they would not often be used. Under such conditions it would naturally be impossible to know how the reading of the instrument would be used, without making some test by inserting reactance or capacity in the potential circuit of the wattmeter. By varying this reactance or capacity it is possible to observe whether the reading is due to the influence of the phase displacement in the transformers overpowering the action of the energy flowing in the circuit or whether the two forces are acting in the same direction on the instrument. This aspect of the question is referred to only to make it clear that such a condition may arise and that it has been considered. On the other hand, it is quite evident that no such condition could arise unless the power-factor of the circuit to be measured is extremely low or unless the sum of the correction angles was comparatively very large. This would mean that the correction factor would be so large that a very small error in the correction angle would render the results worthless.

The intention is not to discuss the design of current and potential transformers, but rather to consider the best means which may be employed to determine their corrections, and to apply the results of these tests to any measurements that may be made, with reasonable accuracy, using any given combined apparatus. Under some circumstances it is necessary, especially with current transformers, to determine the ratio and phase-angle by indirect methods, and as these indirect methods involve a general understanding of the theoretical elements of current transformers, this part of the subject will be dealt with only to the extent which is necessary. The potential transformer may not need such consideration in this place as the theory of transformers operating at constant potential has been much more fully dealt with. The current transformer has of course, received the attention of several writers, but these articles have in general been theoretical and have not been expanded in sufficient detail to be useful to those who require quantitative results.

THE CURRENT TRANSFORMER

The current circulating in the primary of the current transformer may be considered as consisting of two components, the current appearing in the secondary and the current necessary to excite the core. These two components are not usually combined in a straight line. In order to consider the relation between the exciting current, the primary and the secondary current, reference may be made to the diagram in Fig. 1. The magnitude of the exciting current is very small in comparison with the primary and the secondary currents, and therefore is not drawn to scale in the diagram. On account of the small relative value of the magnetizing current it is usually much more convenient and accurate to compute the ratio and phase-angle from the exciting current or to compute the exciting current from careful ratio and phase-angle tests, than it is to attempt to scale the diagram, although the diagram is useful as an aid in obtaining a clear conception of the operation of the transformer. In the diagram i_e is the exciting current plotted as ampere-turns. I_s is the secondary current plotted as ampere-turns



i_e = EXCITING CURRENT PLOTTED AS AMPERE TURNS.
I_s = SECONDARY CURRENT PLOTTED AS AMPERE TURNS AND WITH ANGLE θ_s CORRESPONDING TO P.F. OF SECONDARY LOAD EXTERNAL AND INTERNAL.
I_p = PRIMARY CURRENT PLOTTED AS AMPERE TURNS REVERSED.
α_e = ANGLE OF LAG OF EXCITING CURRENT.
β = ANGLE BETWEEN PRIMARY AND SECONDARY CURRENTS.
θ_s = ANGLE OF LAG OF SECONDARY CURRENT EXTERNAL AND INTERNAL
θ_p = ANGLE OF LAG OF PRIMARY CURRENT.

FIG. 1.—Diagram of current transformer

making an angle θ_s corresponding to the power-factor of the secondary load. This load consists of two parts: that external to the transformer, and that due to the resistance and reactance of the transformer secondary. The reactance of the secondary winding is inappreciable in any transformers that have been examined. I_p is the primary current plotted as ampere-turns reversed. α_e is the angle of lag of the exciting current; β is the angle between primary and secondary current; θ_s is the angle of lag in the secondary circuit considering both the external and internal portions combined; θ_p is the angle of lag of the primary current.

The diagram is drawn with counter clockwise rotation, with the core flux vertical and the induced electromotive force in the core horizontal. The exciting current is plotted as the ampere-turns necessary to produce voltage I_s Z_s where I_s is the secondary current, and Z_s is the total impedance ohms in the secondary circuit.

Examination of the diagram will show that the ratio and phase-angle between the primary and secondary currents depend on the impedance ohms in the secondary circuit, the power-factor of the secondary circuit, the power-factor of the exciting current and the ampere-turns for which the transformer is designed.

The secondary current may lead the primary current by an angle equal to $+\beta$ or it may lag behind the primary current with an angle equal to $-\beta$ depending on whether the secondary power-factor is higher or lower than that of the exciting current. If the power-factors are equal there will be no phase displacement. An examination of the diagram will show also that with non-inductive load on the secondary of the transformer the ratio is affected to a relatively small extent by the magnitude of the exciting current, whereas the phase-angle is greatly influenced under these conditions. On the other hand, when the power-factor in the secondary circuit is lower and approximately that of the core, the exciting current is fully effective in varying the ratio of the transformer but has little effect on the phase-angle. With the information which we now have at hand it is possible to outline the tests which should be made on a current transformer in order that its performance under conditions of use may be known.

It is useful to know how the ratio and phase-angle are affected by variations in the frequency, in the line current, in the impedance of the secondary circuit, in the power-factor of the secondary circuit, or in the wave-form of the primary current. Small changes of frequency have little effect on the ratio. Tests made at 60 and 25 cycles will give sufficient data from which ratios, for intermediate cycles, can be readily obtained by interpolation when required.

Variations in line current affect the ratio of the transformer because the exciting current necessary to produce the required potential to force the secondary current through its circuit is not proportional to the current flowing with a given connected secondary load. Much can be done with a suitable design to control this action, but any commercial transformer should be tested between the limits of 0.1 load and full load before it can be relied upon for accurate measurements, or if the transformer is one of a general type it may be satisfactory to make a short test to determine the quality of the core and rely on more general tests on the same type for complete information on the transformer.

Variations in the impedance of the secondary circuit affect the ratio and phase-angle of the transformer, and, as before stated, the power-factor of the connected secondary load has a bearing on the ratio and phase-angle resulting. It is therefore necessary in making a complete test on a transformer, to test it on various power-factors, and with each power-factor to increase the impedance from minimum to maximum value. Such a test, however, consumes almost too much time, even for a standard test on a few transformers to obtain the characteristics of a type.

In practice it is quite usual to find that the secondary loads of small impedance have a comparatively high power-factor, and that the larger loads are usually of higher relative reactance. For this reason it is satisfactory to make a general test of a transformer, using the two frequencies above referred to, 25 and 60 cycles, and 5 loads which cover practically a range from a single instrument and a few feet of wire to a trip coil for the direct operation of an oil switch. For very accurate work it is sometimes useful to tabulate or draw a curve for another load in which there is no sensible impedance in the secondary circuit other than that offered by the secondary winding of the transformer itself. This zero load may be determined by interpolation from the tests made on the other loads and is chiefly of value when the transformer is to be used in connection with a single induction meter. The characteristics of these loads, which have been used in tests referred to later, are as follows:

All of the loads were tested using 5 amperes and 60 cycles, and any other load which is to be used on a transformer may be tested or computed by addition of the separate items, after being tested on the same basis. It has been found more convenient perhaps without good reason, to designate a given transformer load as a certain number of volt-amperes rather than to reduce it to resistance-reactance components unless the power-factor is quite different from that of the standard load with which it is to be compared.

	Amperes	Volts	Watts	Volt-amperes	Power-factor	Resistance	Ractance X 60 cycles
Load No. 1..........	5	2.104	8.32	10.52	0.79	0.3325	0.1578
Load No. 2..........	5	3.72	15.34	18.6	0.829	0.6168	0.4167
Load No. 3..........	5	4.98	16.06	24.9	0.645	0.6423	0.7615
Load No. 4..........	5	9.36	22.9	46.8	0.489	0.9155	1.6325
Load No. 5..........	5	27.5	49.09	137.5	0.357	1.964	5.140

These loads may be represented, in commercial instruments, about as follows:

Load No. 1, portable ammeter, portable wattmeter, and 50-ft. leads of No. 10 wire, (100 ft. of wire) or two station instruments and 15-ft. leads, or one station instrument and 200-ft. leads.

Load No. 2, same as load 1, with the addition of one station instrument or two portable instruments.

Load No. 3, two station instruments, relay, and 50-ft. loads.

Load No. 4, the maximum number of station instruments, up to four or five in number, in combination with a relay and leads.

Load No. 5, one coil, for directly tripping an oil switch in combination with ammeters and leads.

All the information given, covering the way in which the loads are made up, is only very approximate, and to determine the performance of any given transformer which has been tested on the above loads, definite knowledge should be had of the particular load on which it is to be used before the desired information can be obtained for the test records. The foregoing loads are only for use in testing transformers which have been designed for general switchboard requirements. Of course, transformers of smaller capacity, built for some special or specific use, will require testing only on the loads with which they are to be used.

There are many methods which may be employed to determine the ratio of current transformers. The most obvious one, and that which may be employed successfully, if a high degree of accuracy is not required, is to measure the primary and secondary current by means of any alternating-current ammeters which may be available. Unless some special equipment is available for measuring the primary current, and if this current is beyond the capacity of the comparatively small range of commercial instruments, the test finally resolves itself into a comparison between two current transformers, as a second transformer must be made use of, in connection with the primary ammeter. If a good, carefully checked, variable-ratio current transformer is available for the purpose, in combination with two good ammeters, the results obtained are quite satisfactory. It is not possible by this means to accurately determine the ratio down to a small primary current, say 10 per cent of maximum, which is required in connection with wattmeters.

It is not advisable to attempt to obtain lower current values, by using a smaller capacity instrument in the secondary, because of the change which this brings about in the impedance of the secondary circuit. If the transformer is a very good one, this change may result in a comparatively small error, but in such a transformer the difference in the value obtained at 10 per cent and, say, 25 per cent of primary current would be rather small. In general it is believed that if anything at all is known of the characteristics of the transformer, that a closer approximation to the true ratio value at 0.1 load may be obtained by exterpolating the lower part of the curve than by attempting a measurement with small capacity instruments on the secondary.

Ratio determinations made with small-capacity ammeters have been used in connection with 5-ampere-capacity wattmeters, resulting in considerable error where a high degree of accuracy is required. Wattmeters give a better indication lower down on the scale than ammeters usually do, so that the temptation to use these instruments of small current capacity is not as great as with ammeters. However, if this is done not only is the ratio affected but the error due to phase-angle is usually increased. To illustrate this point still further, a portable 5-ampere ammeter requires about one volt to force through it full-capacity current, or 5 volt-amperes. A two-ampere instrument, having the same number of ampere-turns, requires 2.5 volts at 2 amperes, or for comparison with the 5-ampere instrument, 6.25 volts at 5 amperes, and acts on the transformer as a load equivalent to a little more than 36 volt-amperes, a load about half way between the number 3 and 4 loads which have been used in the tests.

If the transformers are to be used with the same instruments with which they are tested, of course instruments of any capacity or impedance may be included in the secondary circuit. This error has been made many times.

Even before the manufacture of current transformers was undertaken commercially, it was apparent that accurate ratio determinations under widely varying conditions required some special arrangement to do the work with a high enough degree of accuracy so that determinations could be made on transformers independent of their being combined with any specific instruments. As soon as work was started the fact also became apparent that the current transformer was a very accurate and reliable device. The effect of the exciting current is comparatively small, and may be varied within wide limits without affecting, except to a small degree, the ratio and phase-angle. The current transformer is by no means a perfect device, because it cannot give a constant ratio or phase-angle with change of primary current or secondary load. However, these errors may be reduced by careful design to almost any size, and if they have once been accurately determined they cannot change in any sensible amount, by reason of any changes which may occur in the exciting current due to variations in the core. This is assuming, of course, that the magnetic material of the core has been suitably chosen, and has received proper treatment so that it may remain permanent.

The following schemes for determining ratio and phase-angle have been tried with more or less success; they have all been satisfactory as far as accuracy goes, but with some of them the time required is at present too long to make it possible to use the methods in practical work.

METHOD OF DETERMINING RATIO AND PHASE-ANGLE BY REFLECTING DYNAMOMETERS

Referring to Fig. 2, the fixed coil of the primary dynamometer is connected in series with a shunt to the source of supply. The moving coil of the dynamometer is applied to the drop terminals of the shunt, and included in this potential circuit is the resistance r_p. Choosing suitable values for r_p and for the shunt resistance R_p, the combinations can be arranged to give a good deflection at from 0.1 to full rated primary current. The secondary is provided with a similar arrangement, usually of 5 amperes maximum capacity. In this circuit the energy to operate the combination must be limited. As usually arranged the secondary requires about 2 volts with full-load current of about 5 amperes, and is the No. 1 load referred to in the test.

The primary and secondary dynamometers are first carefully checked on direct current by means of a potentiometer. The test is then made and the ratio determined by dividing the primary current by the secondary current. In actual testing the primary current is brought up to the calibrated point and the secondary current is read. The scale reading obtained in calibrating the secondary dynamometer at the current corresponding to the correct ratio, is then divided by the reading obtained with the correct primary current, and the square root of the result is the accuracy of ratio. The instruments used

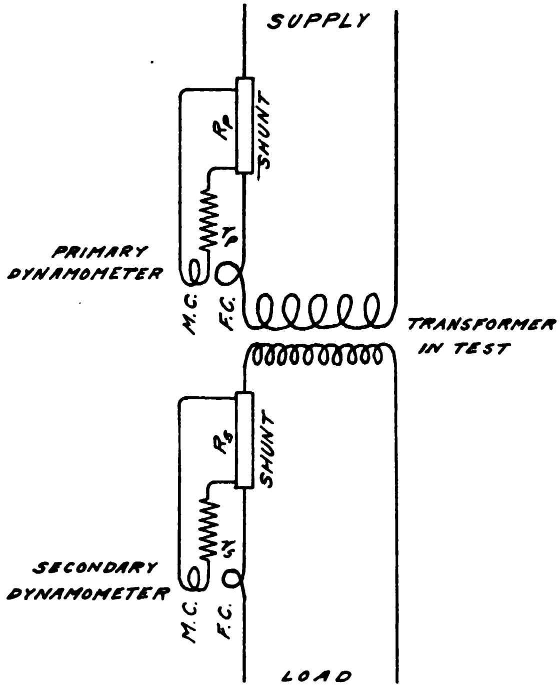


FIG. 2.—Connections for ratio test on current transformer by two dynamometer method

measure the watts lost in the shunt resistance, and, therefore, give a deflection proportional to the current squared. It has been found more convenient to express this ratio as that of a 1:1 transformer, or to write the true ratio divided by the marked ratio, than to use the actual ratio of transformation, as by this means transformers of the same type may be directly compared although their current capacity is quite different. In common with any other method in which the primary and secondary currents are actually measured and used to compute the ratio of the transformers, this method would not appear at first sight to be satisfactory either from the standpoint of accuracy or speed. It depends, of course, entirely on the accuracy which may be secured with the instruments used. The results obtained in this way have been more satisfactory, so far, than by any other method. In Fig. 3, connections are shown for determining the phase-angle between the primary and secondary

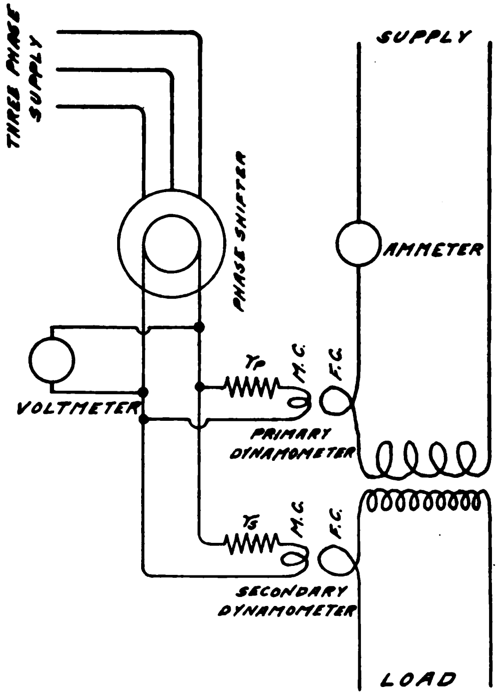


FIG. 3.—Connections for phase-angle test on current transformer by two dynamometer method

currents. Dynamometers are the same as used for the ratio determination as in Fig. 2. The current windings are in the primary and secondary as before, but the current-carrying resistances are not necessary, except to keep the secondary load unchanged. The potential coils of the instrument are connected to a phase-shifter, shown in the diagram, this phase-shifter being rotated until the primary dynamometer reads zero. The phase-angle then is,

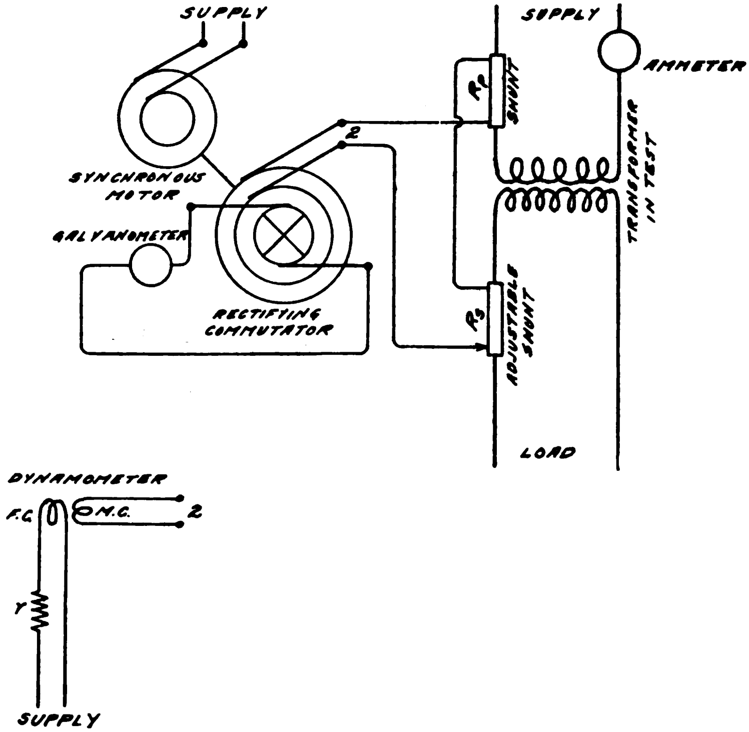


FIG. 4.—Connections for ratio test on current transformer by comparison of resistances, using dynamometer or rectifying commutator and galvanometer

$$\beta = \sin^{-1} \frac{W_s}{I_s \times E}$$

where I_s is the secondary current in the transformer, as before,

W_s is the watts read on the dynamometer and E is the voltage on the phase-shifter, at the point where the potential coil is attached. It is worth while mentioning here that to secure accurate results the resistances r_p and r_s must be practically perfect and without inductance or capacity, and if the moving coils have appreciable inductance the L/r of the circuits must

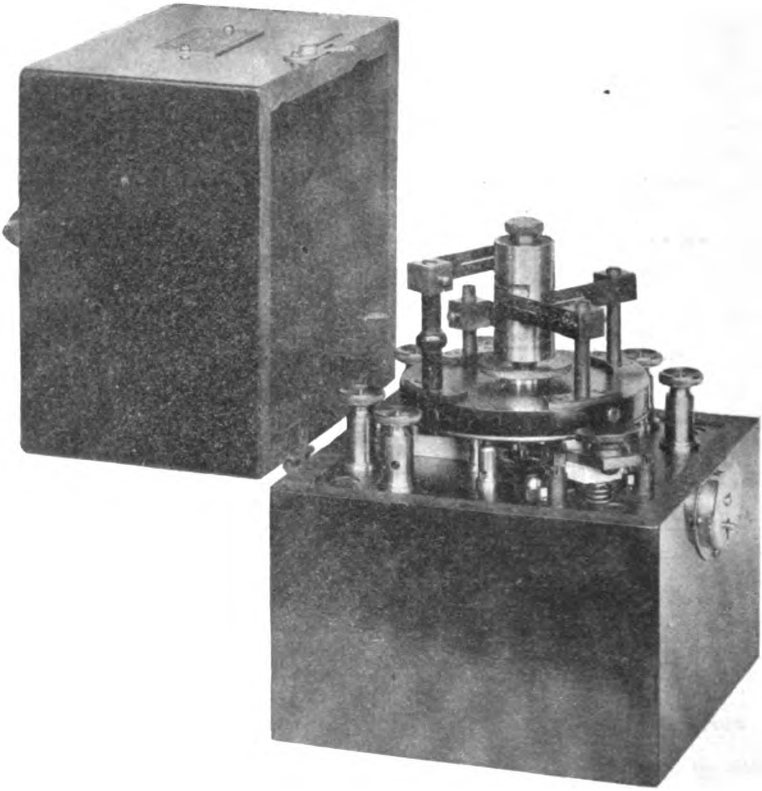


FIG. 5.—Rectifying commutator

be equal. In the actual tests referred to it has been found best to make the inductance of the moving coil practically zero.

Referring to Fig. 4, suitable non-inductive resistances or shunts, one fixed and one adjustable, are included in the primary and secondary circuits. After connecting as shown in the figure, it is only necessary to make use of some form of sensitive alternating-current galvanometer to show when the potential drop on the two shunts balances. The secondary shunt is adjusted until this balance is secured, then the ratio equals $\frac{R_s}{R_p}$. The equality of potential can be shown by a rectifying commutator in combination with a direct-current galvanometer, or

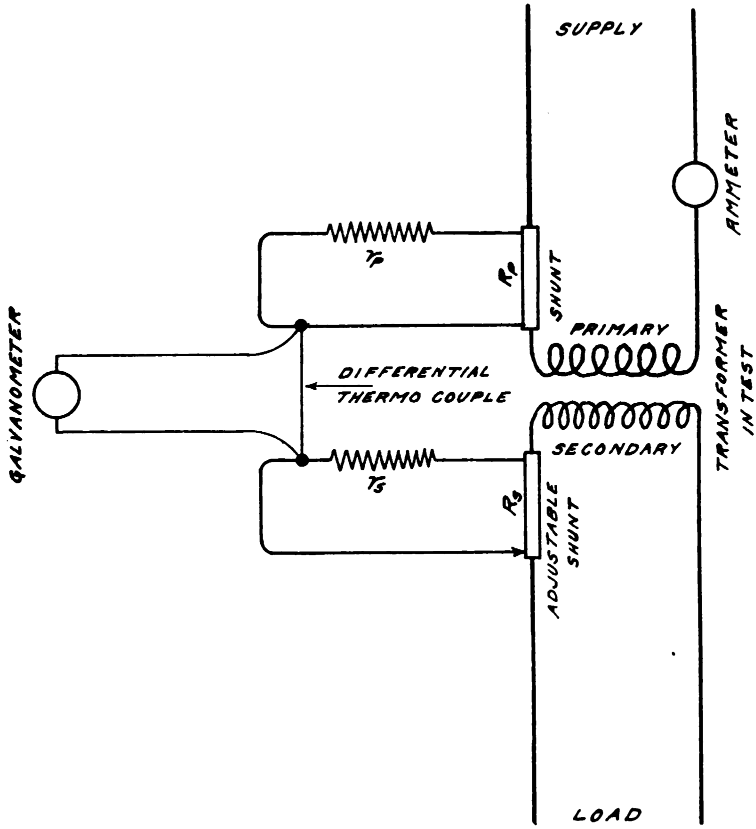


FIG. 6.—Connections for ratio test on current transformer by comparison of resistances, using differential thermo-couple and galvanometer

by using the moving coil of one of the reflecting dynamometers, the fixed coil of which is energized from any convenient point of the same circuit. Fig. 5 shows a rectifying commutator driven by a synchronous motor, which has been developed for this use.

Fig. 6 shows another way of determining the ratio by means of current-carrying resistances and an alternating-current comparator of any suitable type. The expansion comparator of Dr. Northrup has been used for this method, and also a thermo comparator, as shown in the figure. The experiment of using a differential dynamometer has also been tried, but without any very satisfactory results. It is hoped that one of the illustrated schemes for directly determining the ratio will ultimately be found more accurate and convenient than the two dynamometer methods now being used. But so far, owing to various minor difficulties, the time required to test in any of these direct ways is much longer, and the accuracy is no better than that obtained by using the first method in Fig. 2.

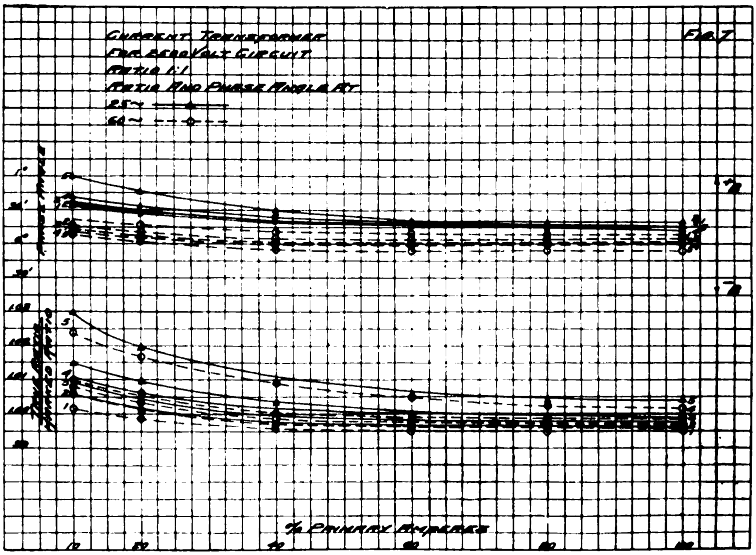


Fig. 7.—Full test (loads Nos. 1, 2, 3, 4 and 5) on current transformer for 2500 volt circuit

In order to show the general character of the tests as outlined, and to bring out clearly the fact that tests made by the method referred to in connection with Figs. 2 and 3 are satisfactory, as far as accuracy of results is concerned, two complete tests are shown in Figs. 7 and 8. It will be seen that the observed points lie very closely on the smooth curves. It can also be seen that the observations must be made with considerable precision, else the curves cannot be plotted with sufficient accuracy to be clearly read. This is especially true of the phase-angle tests.

It is possible to extend the capacity of the methods referred to up to any required current value; but with either the dynamometer or shunt methods great difficulties are encountered in producing instruments or shunts of very large capacities in which the eddy currents or other disturbing causes have been eliminated to the required extent. For this reason the expedient was tried of calculating the ratio and phase-angle of current transformers, from the exciting current determined by means of a sensitive reflecting dynamometer similar to those used for ratio determinations. Another instrument of the same class was used for determining the watts lost in the core. From the indications of these instruments may be plotted exciting current against volts produced on the secondary of the transformer and a second curve of volts and power-factor. From these the amount and apparent angle of the exciting current can be read for use in calculating the ratio and phase-angle. From the transformer diagram in Fig. 1, the following expressions for ratio and phase-angle can be obtained in terms of the exciting ampere-turns:

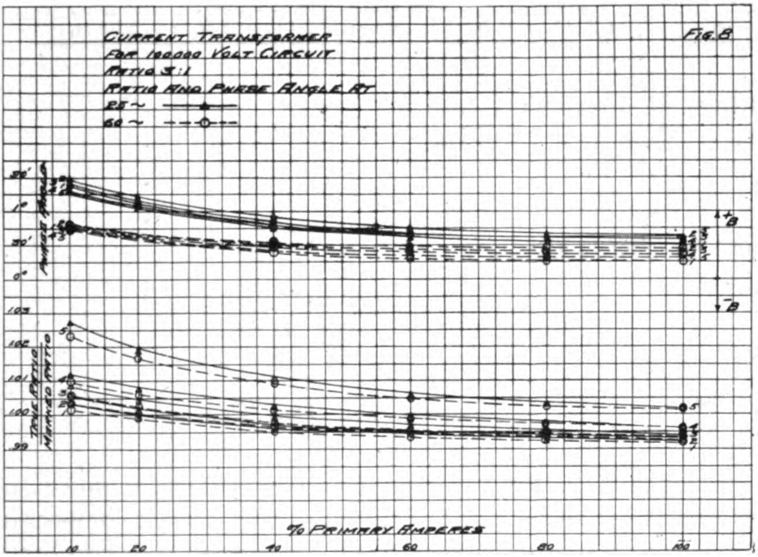


FIG. 8.—Full test (loads Nos. 1, 2, 3, 4 and 5) on current transformer for 100,000 volt circuit

Ratio =

$$\frac{I_p}{\sqrt{(I_p \cos \theta_p - i_e \cos \alpha_e)^2 + (I_p \sin \theta_p - i_e \sin \alpha_e)^2}}$$

where I_p = primary current in ampere-turns
θ_p = its angle of lag
i_e = exciting current in ampere-turns
α_e = its angle of lag.

As the calculations are usually made on the basis of given conditions in the secondary circuit we can write

$$\text{Ratio} = \sqrt{\frac{(I_s \cos \theta_s + i_e \cos \alpha_e)^2 + (I_s \sin \theta_s + i_e \sin \alpha_e)^2}{I_s}}$$

where I_s = secondary current
θ_s = its angle of lag
i_e = exciting current
α_e = its angle of lag

and for phase-angle

$$\beta = \tan^{-1} \frac{i_e \sin (\alpha_e - \theta_s)}{I_s + i_e \cos (\alpha_e - \theta_s)}$$

or

$$\beta = \sin^{-1} \frac{i_e \sin (\alpha_e - \theta_s)}{I_p}$$

In all the foregoing formulas the currents i_e and I_p and I_s are expressed in ampere-turns. As it is usual to partly compensate for the effect of exciting current on the ratio of the transformer by winding the secondary of a transformer with a few turns less than the primary turns times the marked ratio, this fact must not be overlooked in the calculations, and the actual number of secondary turns must be used. In certain cases it may be useful to work out, for comparison, exciting-current values from tests on ratio and phase-angle to compare tested points with those obtained by calculation. For this purpose we can write,

$$i_e = I_s \sqrt{R^2 - 2R \cos \beta + 1}$$

$$\sin (\alpha_e - \theta_s) = \frac{I_p \sin \beta}{i_e}$$

Of course, only a rough idea of the exciting current values can be obtained in this way, but when it is pointed out that a 0.1-per cent error in a ratio determination may easily cause 10 per cent error in the exciting current determined in this way, the explanation is sufficient.

The computer should not be misled by the fact that an exciting-current curve may frequently be computed back in this way, and pass evenly through all the points. This would simply indicate that a smooth curve had been drawn through the ratio determinations, and accurately read before being introduced in the calculations.

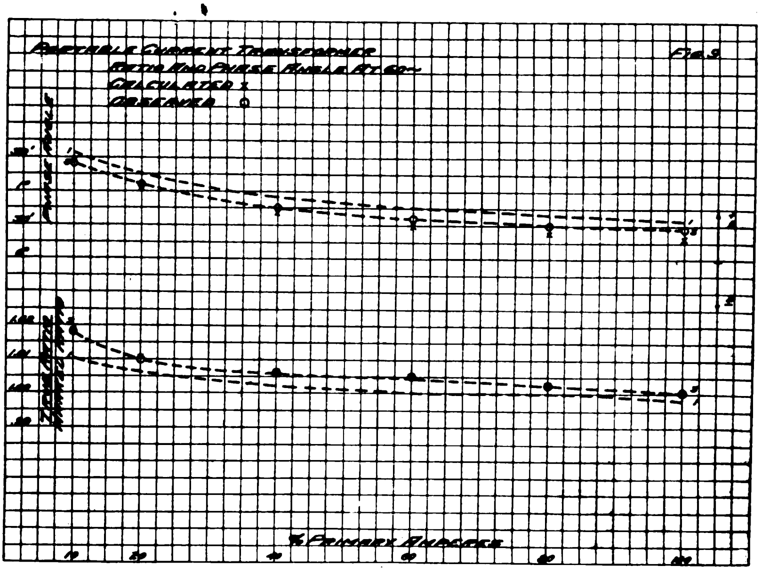


Fig. 9.—Comparison between observed and calculated ratio and phase angle on portable variable ratio current transformer

In Fig. 9 are shown ratio and phase-angle determinations on a portable transformer for variable ratio; in this transformer the primary winding is wound in by the user, to meet the immediate requirements. This test was made on 60 cycles, using No. 3 load. The calculated and observed points have all been plotted. From this it can be seen that the calculated values agree with the observations well within the limits of accuracy expected. The phase-angle values have also been computed, and are shown in the same way. The agreement here is also satisfactory, and the method can be applied to transformers of any capacity. The reason for choosing the portable transformer of comparatively small ampere capacity in preference to a large bus-bar transformer, is because of the difficulty in determining the large primary current by methods that would be above suspicion.

THE POTENTIAL TRANSFORMER

The same general considerations which apply to current transformers may be expanded to cover the potential transformers. As before stated this will not be done at the present time, both because the subject has received more general attention, and because the determinations of the ratio and phase-angle, even with comparatively high primary voltages, are much easier to make than similar tests on the current transformers. It is possible, using the apparatus about to be described and without a prohibitive expenditure of time, to test a potential transformer on any frequency with the secondary loaded from a single high-resistance instrument up to its maximum rated capacity. If convenient means are at hand it is also possible to quickly determine by test the ratio and phase-angle when the power-factor of the connected secondary load varies between any desired limit. Such a complete test is

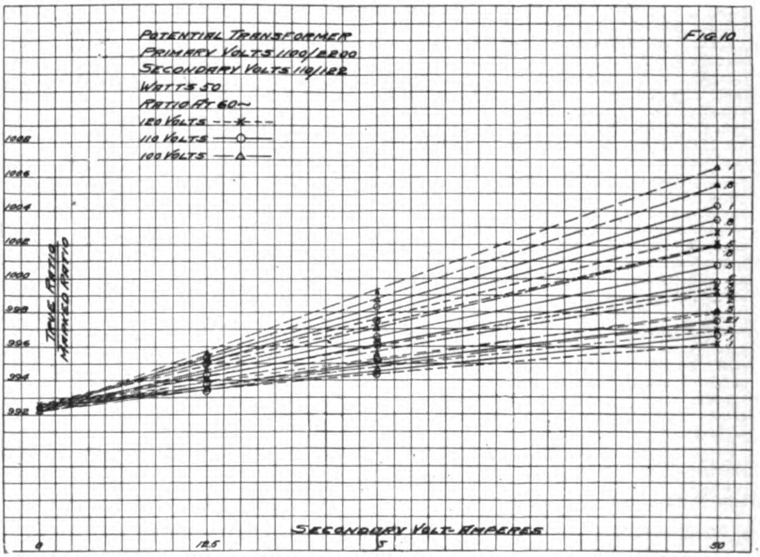


FIG. 10.—Full test of ratio on potential transformer

shown in Figs. 10 and 11. Various methods have been used for this work, as well as for current-transformer testing, but the one finally chosen has been found so convenient and accurate that no other special device will be referred to, in connection with the testing of potential transformers.

Referring to Fig. 12, and to Figs. 13, 14 and 15, a complete equipment is shown, especially constructed to produce transformer tests, of the general kind shown in Figs. 10 and 11. This is suitable for use on any frequency, and up to 33,000 volts. Additional resistance may be coupled to the standard arrangement, so that the range may be temporarily extended to any desired limit. The resistances r_1 and r_2 are connected across the primary circuit with taps for various voltages, so that about 10 ohms per volt may be used. The primary and secondary are connected together and to the ground as shown. The polarity is such that the potential rise from ground along the secondary of the transformer, is in the same direction as that from ground along the main primary resistance. Then a point may be found in the primary resistance which is at the same potential as the high side of the secondary. We then have,

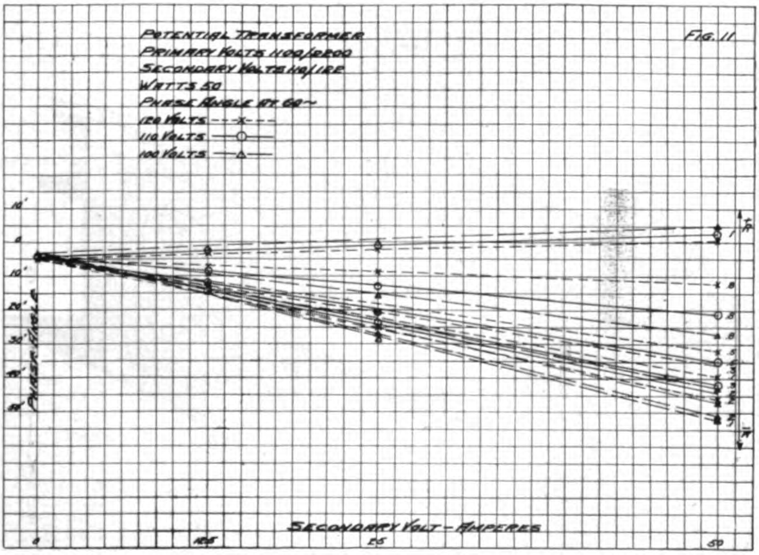


FIG. 11.—Full test of phase angle on potential transformer

$$\text{Ratio} = \frac{r_1 + r_2}{r_2}$$

The equality of potential is determined by a dynamometer, referred to in Fig. 4, or by a synchronous commutator, as shown in Fig. 13. The apparatus is made direct reading to within 0.1 per cent between the limits of 5 per cent below and 5 per cent above the marked ratio of any transformer, by employing the 100-point switch shown in Fig. 12. The movable contact, by which the potential coil of the dynamometer is moved along the primary high resistance, may be advanced by 1-ohm steps. Arranged in this way the ratio observations can be made as rapidly as they can be recorded, and values may be interpolated to 0.01 per cent if desired. The arrangements

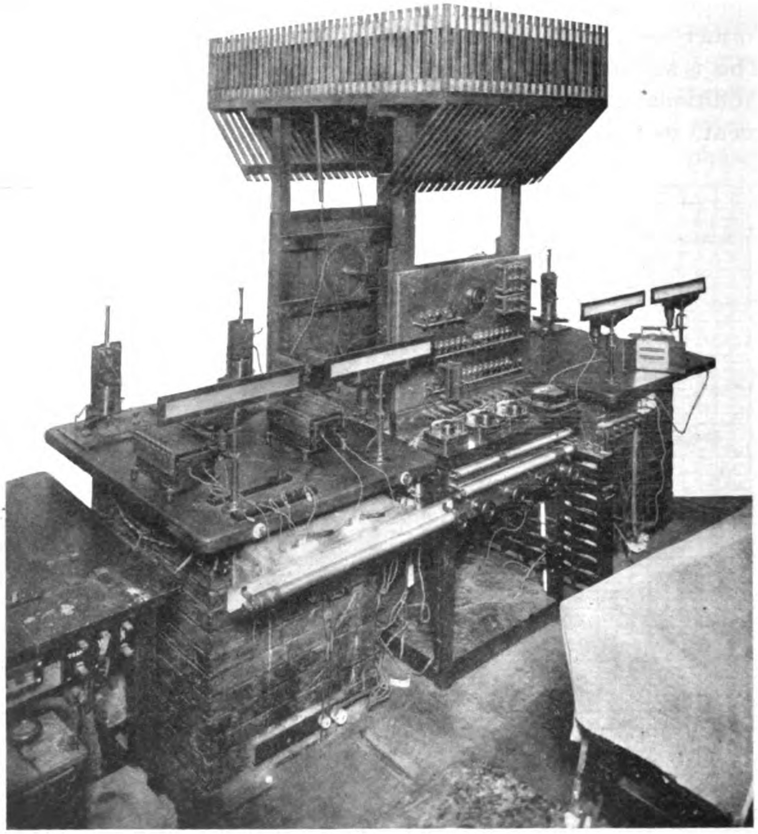


FIG. 12.—Outfit for ratio and phase angle test on potential transformers referred to in Fig. 8

provided for loading the transformers are shown in Fig. 15. Reactances are provided taking about 0.12 ampere at 110 volts and 60 cycles, and having a power-factor of about 10 per cent, together with another set of reactances taking about 0.15 ampere at 25 cycles and having about the same power-factor. These may be combined in various ways so that the reactance load at low power-factor may be put on the transformers up to about 2 amperes. Resistance load, variable by much finer

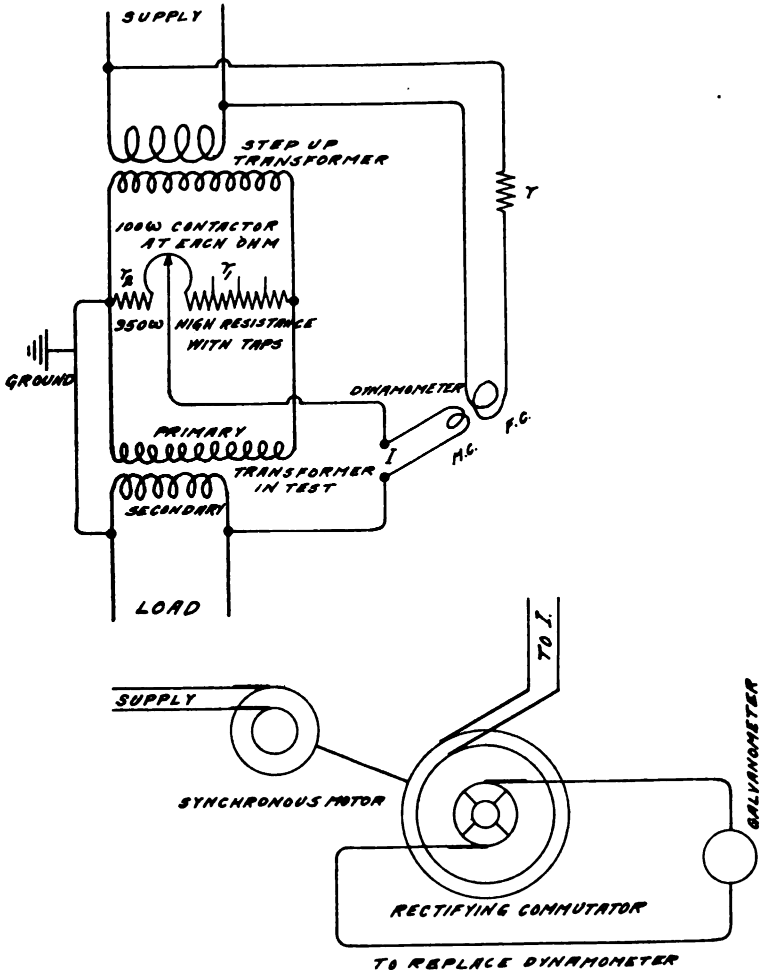


Fig. 13.—Connections for ratio test on potential transformer

steps, is also available up to the same ampere capacity. By combining these in suitable ways, the desired load at any power-factor can be accurately obtained between the limits of 0.1 power-factor and unity. To avoid the time required to make adjustment of load, tables have been prepared by computations from instrument readings. By means of these tables, approximately any ampere load at a definite power-factor can be arranged at once. It is not important to have the load in amperes very exact, as the lines connecting the observed points are practically straight, but the power-factor must be accurately adjusted to plot as shown in Figs. 10 and 11.

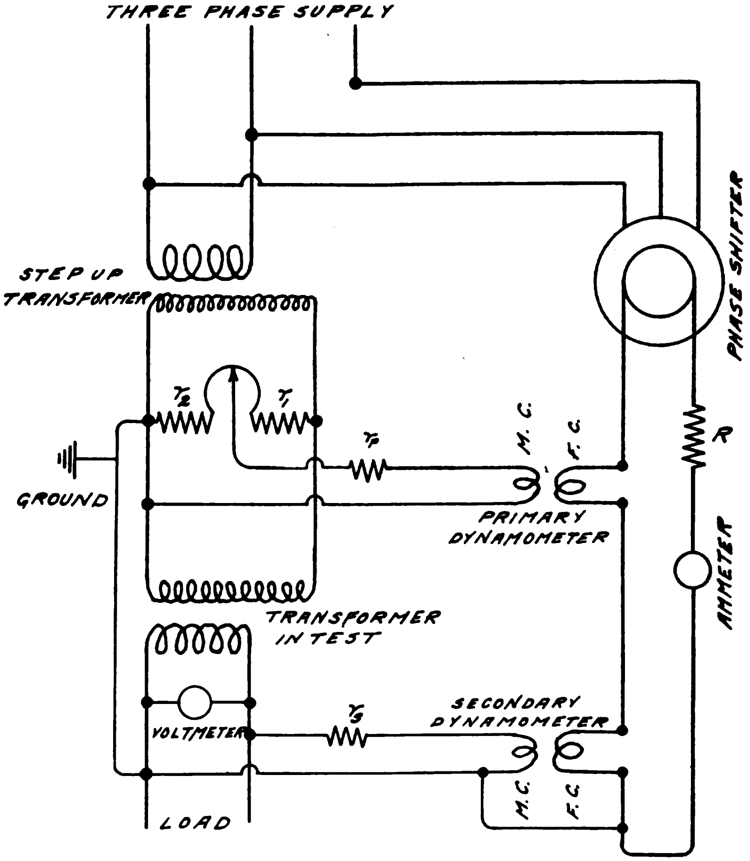


FIG. 14.—Connections for phase angle test on potential transformer

The phase-angle is determined on the potential transformers

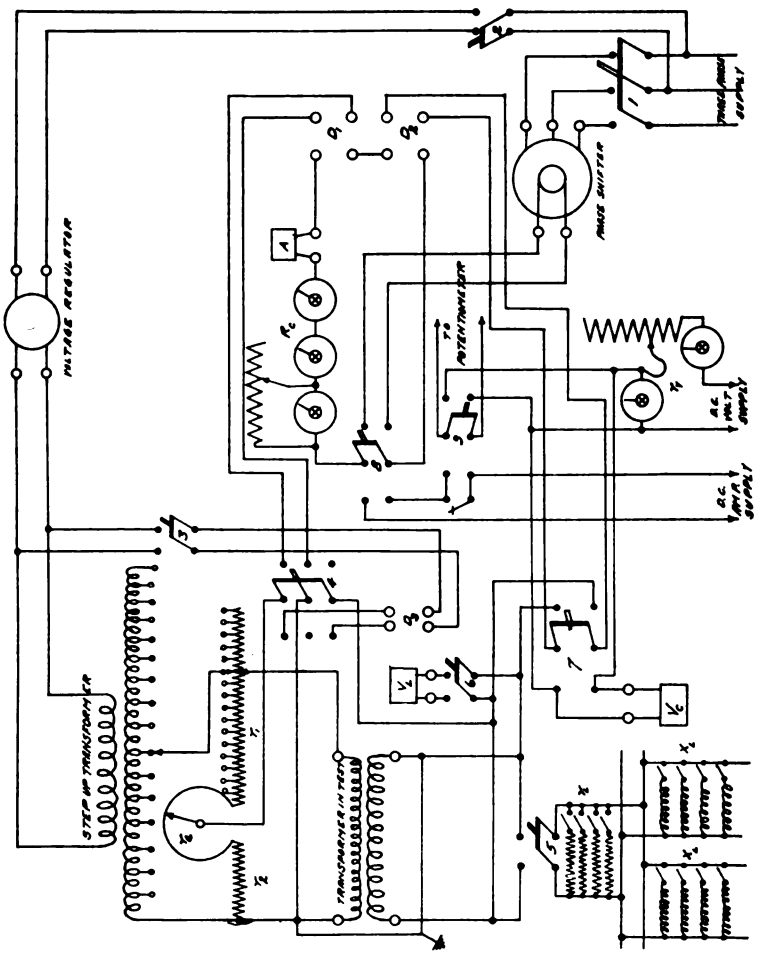


FIG. 15.—Diagram of connections of outfit for ratio and phase angle test on potential transformers. (1) Main switch on phase shifter. (2) Main switch on transformer supply. (3) Switch for exciting stationary coils of dynamometer for ratio test. (4) Main transfer switch; to left for ratio test, to right for phase angle test. (5) Main load switch. (6) A.C. voltmeter switch. (7) Secondary dynamometer potential coil switch. To right for phase angle test, to left for D.C. calibration, open for ratio test. (8) Dynamometer current switch. To right for phase angle, to left for D.C. calibration. (9) Potentiometer switch; to left to place potentiometer leads in series with D.C. for wattmeter calibration: to right to place potentiometer leads in multiple with D.C. voltmeter for calibration. r_1 high resistance with taps. r_2 950 ohms. r_a 100 ohms in 1 ohms steps for adjustment of moving contact. r_l resistances to furnish load for secondary. x_l reactance coils to furnish load for secondary. V_L A.C. voltmeter. V_c D.C. voltmeter for calibration. r_v resistances to regulate voltage applied in calibration. R_c resistances for control of current (A.C. or D.C.) applied to dynamometers. D_1, D_2 dynamometers with suitable resistances in series with potential circuits for determining phase angle. D_3 dynamometer with suitable resistances in series for ratio test.

in somewhat the same way as already described for current transformers. The connections used are shown in Fig. 14, and the complete connections as used in the device in Fig. 15.

The 3-phase or 2-phase line current is brought to a phase-shifter and to the low-voltage side of a step-up transformer. A duplicate of the transformer being tested may frequently be used for stepping up the voltage. Current from the secondary of the phase-shifter is passed in series through the current coils of two dynamometers, usually of 5-ampere capacity, the amount being controlled by a suitable resistance *R* in series. By varying the current passing through *R* and the fixed coils, the sensibility of the arrangement may be made as desired. The same resistance used in the Fig. 13, ratio test, is connected in multiple with the primary of the transformer in test, and the drop across a considerable portion of it is used to excite the moving coil of the primary dynamometer. The resistances r_p, r_1, r_2, and r_s must be practically perfect, as in phase-angle testing of current transformers. The secondary voltage of the transformer under test is used to excite the potential coil of the secondary dynamometer through the resistance r_s. The current coil and the potential coil on the secondary dynamometer must be connected together, as shown. The load on the transformer under test is then adjusted to the proper current and power-factor, and the phase is shifted until the primary dynamometer reads zero. The phase-angle between the primary and secondary electromotive force is then,

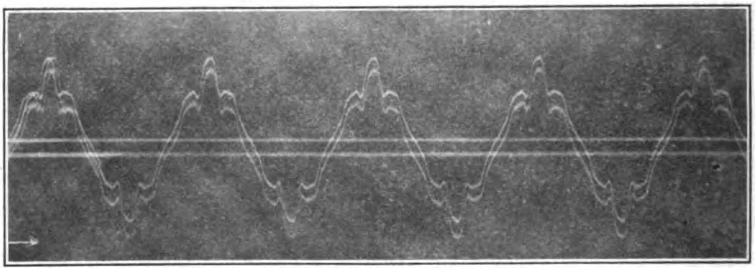


FIG. 16.—Primary and secondary current waves on portable current transformer with load No. 1, and 25 per cent of full primary amperes 60 cycles

$$\gamma = \sin^{-1} \frac{W_s}{E \times A}$$

Where W_s, E and A have the same meaning as in the formula for phase-angle on the current transformer.

The voltmeter V, is used to regulate the test voltage on a transformer, and if it is left on during the test, it must be considered as part of the transformer load.

Before leaving the general subject of instrument transformers it may be well to refer to one point about which some uncertainty exists; namely, the effect of current transformers in causing a wave to appear in the secondary circuit, differing in form from that of the primary. As the shortest and most satisfactory way of disposing of this point, oscillograph records, Figs. 16, 17 and 18 have been taken, showing primary and secondary current waves in a current transformer. Examination of these figures will show that the primary wave is reproduced, practically unchanged, in the secondary. A much distorted wave was purposely chosen.

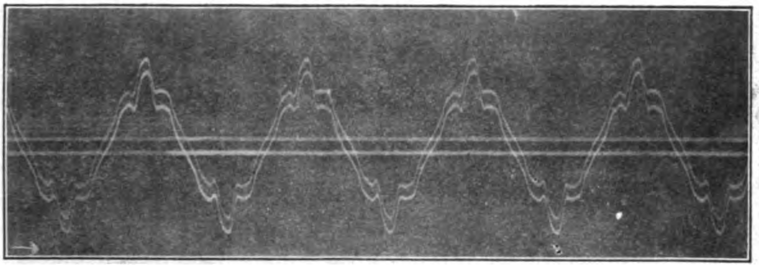


FIG. 17.—Primary and secondary current wave on portable current transformer with load No. 1 and 50 per cent of full primary amperes 60 cycles

CONCLUSIONS

For measuring large alternating currents and voltages, current and potential transformers must usually be employed. If these are carefully designed they may be used with small errors resulting with various devices connected in the secondary circuit, and with primary current varying between the limits of the connected instrument scales, also with voltage and frequency variation usually met with in practice. If some care is not used in selecting suitable apparatus to meet conditions, errors as great as 5 or 10 per cent or more may occur. If the transformers are constructed with special reference to handling a given load, the errors may be limited to almost any required amount. To meet conditions of testing where low power-factor is present, or where a high degree of accuracy must be attained, carefully determined corrections for ratio and phase-angle must be applied. Such corrections, once determined for any given transformer, are permanent, and by their use the transformers may be considered precision instruments.

Wattmeters, when used without current or potential transformers, may be made to give indications correct within the limits of error of observation down to a power-factor as low as 10 or 15 per cent. Under certain conditions which may occur in practical work, it is well to know and apply corrections to the instruments themselves. If the conditions are such that the wattmeter must be corrected for phase-angle to insure suitable accuracy, current and potential transformers should not be used, unless the conditions are somewhat favorable, and the corrections for the transformers are determined and applied with great care.

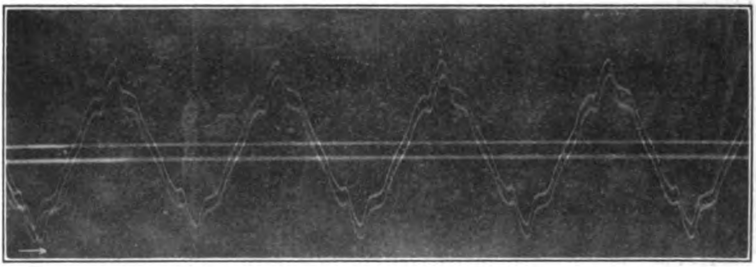


Fig. 18.—Primary and secondary current waves on portable current transformer with load No. 1 and 100 per cent primary amperes 60 cycles

In presenting the foregoing on the use of instruments in connection with current and potential transformers, it is perhaps proper to say that a considerable part of the subject matter contained therein has received more or less complete treatment in various publications. An incomplete list of such articles is here given. The paper should be considered as an attempt to describe, with enough detail to be of practical use, some specific methods of determining and applying corrections to the results obtained. The methods have been selected, after several years experience, as being best suited to the requirements that had to be met from time to time.

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(*Subject to final revision for the Transactions.*)

AUTOMATIC MOTOR CONTROL*

BY H. E. WHITE

Of the various systems for controlling electric motors, none surpass in interest and economic importance those which make use of electrically actuated switches controlled by automatic or semi-automatic means. A few years ago the drum controller was quite sufficient for any motor then in use. Since then the use of larger motors and the need for automatic features, unattainable in a simple manner with drum controllers, have resulted in the development of a great variety of magnetically controlled switches, and of various means for operating them in control systems.

At the present time, contactors may be obtained for handling the current required by the largest motors in use, and it can safely be predicted that in the future with even larger motors, air-break switches of the contactor type with magnetic blowouts will be used more and more for high-voltage current, hitherto thought controllable only by oil switches. Tests have in fact already been made showing that currents of 6600 volts can be successfully handled in this way.

Control by contactors is so universally adapted to service under special conditions, that the advantages which it offers over other devices are worthy of mention. Among these·are:

a. The ability to control motors of any size with facility and with slight muscular effort.

b. The ability to control many motors from one conveniently chosen place.

c. The ability to control large motors from a distance with comparatively inexpensive connecting cables.

[Owing to the late arrival of the manuscript, this paper is printed for use at the convention without giving the author an opportunity to correct the proof.]

d. The ability, in conjunction with overload devices, to predetermine the current input to the motor, either during or after starting.

e. The ability to use sensitive devices, such as pressure gauges or thermostats to start motors operating machines such as pumps or blowers.

f. The ability to obtain " no-voltage release " and automatic re-starting features without additional complication.

g. The ability to secure interchangeability of parts to an extent not possible with any other type of control.

h. The ability to secure automatic stopping by limit switches to prevent overwinding or to stop the motor at predetermined places.

The methods by which these results are attained are best understood by examining the principles of operation with particular reference to which recent designs have been made.

The design of the contactor itself is the one thing on which too much stress cannot be laid, for the reason that on it falls the function of repeatedly opening and closing heavy currents in a reliable manner without frequent inspection or adjustment. Properly designed contactors have the inherent advantage of opening and closing quickly, thereby lessening the duration of the period during which the circuit-closing parts are making poor contact. This poor contact period results in a local fusion of metal with consequent wear. In fact, it is well known to those familiar with this type of apparatus, that the wear on the contacts is due almost entirely to local effects at the instant of making or breaking circuit and only slightly due to the vaporous arc formed. It is largely to this fact that the efficiency of motor control at high voltage is due, since the tendency to fuse the points of contact is proportional to the square of the current value, and not to the voltage. In case the currents are very high, recourse must be had to the use of refractory contacts for which the only commercially available substance is carbon. As to carrying capacity, there is a tendency in recent designs to secure it by forcing the contacts together at considerable pressure, but carefully made experiments show that the gain is greatest for the first increase in pressure on the contacts, so that it does not pay to attempt to carry the pressure too high.

Operation at high contact pressure results in the very important advantage that, when the recoil of the springs takes place at the time the contactor is de-energized, a much quicker opening results. In case the contactor is required to carry a very large current for a long time, an auxiliary laminated copper contact is used. The magnetic blow-out has been found equally effective for both direct and alternating current.

Voltage variation affects the operation of contactors in common with other devices operated by a solenoid. The pull of a solenoid varies approximately as the square of the voltage. As a consequence, any abnormal voltage conditions produce correspondingly increased effects on the contactors. This necessitates, in order that satisfactory operation may be assured, that the amount of copper used in the solenoid must be sufficient to carry the current at full voltage without overheating, and to give at the same time pull enough at low voltage to ensure reliable mechanical action.

In the case of contactors operated by alternating current, laminated magnets are necessary to ensure operation without excessive heating. The action of solenoids on alternating current is quite different from their action on direct current. On alternating current, the tendency is towards constant pull independently of the position of the armature, with a corresponding reduction in magnetizing current as the solenoid closes. On direct current, the pull greatly increases as the solenoid operates. These peculiarities have a direct influence on the comparative action of the two types of contactors. The alternating-current contactor closes at a great speed, almost violently, while the direct-current contactor closes more leisurely, its self-induction tending to slow it down very noticeably. The heat generated in an alternating-current contactor is usually greatest in its iron magnetic circuit due to the high densities required and to the alternating magnetic flux. In the direct-current contactor, the heat is generated entirely in the copper parts carrying current. One peculiarity of the alternating-current contactor is its tendency to hum. This can be reduced to an unobjectionable amount by the use of "pole-shading" devices, and contactors for operation on alternating current will consequently be more extensively used as they become better known.

In applying contactors to the control of motors a so-called *current-limit control* is usually employed. In all of the simpler systems, the contactors are so arranged that as each one closes, it completes the actuating circuit for the next contactor, thereby causing the controlling resistance to be short-circuited step by step. One or more overload relays are so arranged that this progressive action will be interrupted without causing any contactors to be opened whenever the current exceeds a predetermined amount. As soon as the current decreases and the relays fall, the operation is renewed, until finally the motor is operating at full speed. In other cases, the contactors are arranged with their operating coils in multiple with the armature of the motor, so that as the motor starts, the increasing electromotive force across the armature will cause the contactors to operate one by one. This arrangement is known as the *counter-electromotive-force system.*

The last-named system is open to the objection that if the voltage of the supply system is not constant, the operation of the control is interfered with, the result being that if the voltage is low, the contactors may not close at all, while if the voltage is too high they will close too soon. This system is best suited for use with shunt motors and not so well suited to series motors, for the reason that the counter electromotive force of a series motor depends upon the current as well as upon the speed of the motor, so that there is a tendency to cut out all of the resistance in case a contactor closes prematurely.

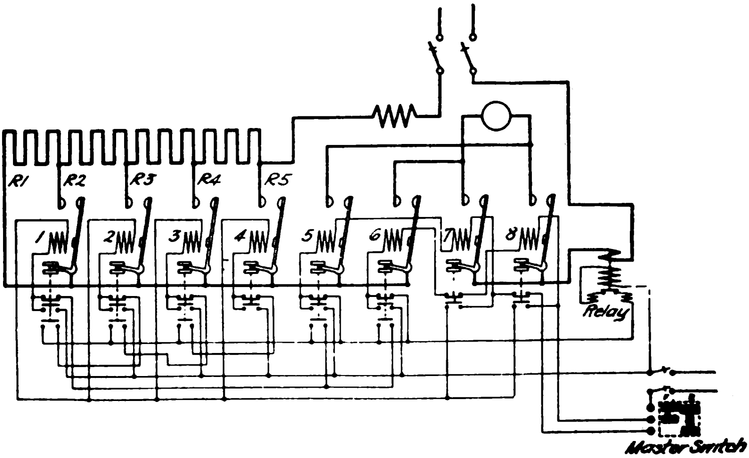

FIG. 1.—Current-limit control with single relay

A modification of this system, using potential relays in multiple with the starting resistance, is so arranged that as the current in the resistance decreases step by step, the relays will fall out and close actuating circuits for the contactors. This modified system is not open to the same objections as the counter-electromotive force system, and is substantially equivalent to current-limit control. In some cases, *time-limit control* is useful; that is, the contactors are arranged so that they will be energized in a given time regardless of other conditions. In this case an escapement or dash-pot is usually employed.

Still another type of control, which may for want of a better descriptive name be called *pilot-motor control,* uses some form of an electric motor to actuate a master switch. This motor can be controlled in any manner desired by overload relays or push-buttons. This system is the one generally used where the control is of a comparatively complicated nature, such as in printing-press work.

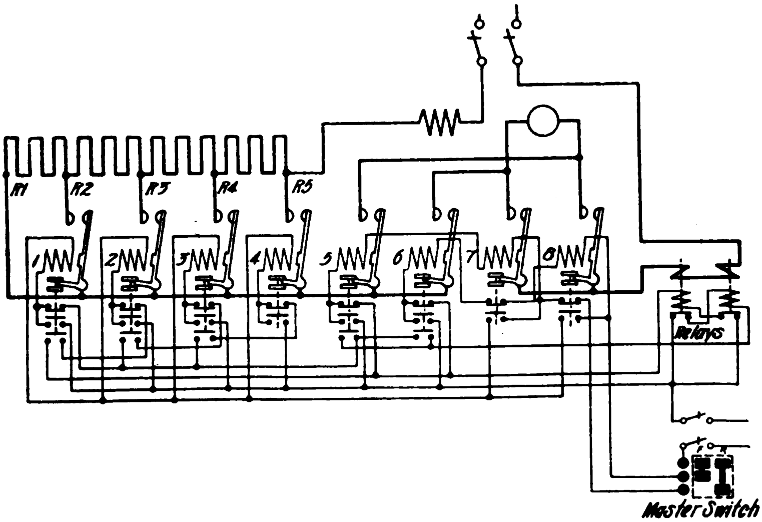

FIG. 2.—Current-limit control with double relay

It is interesting to note that the control of the 2000-h.p. and 6000-h.p. motors at Gary is of this type. In this place, it was used to avoid complicated interlocks on the contactors, which would otherwise have been required to secure the results desired.

The choice of control system to be used in a particular case will be determined by the special conditions governing each case. However, it can truthfully be said that while some of the other systems appear to be specially suitable in some respects, yet current-limit control is always better when all the conditions are considered.

Aside from the current-limit control obtained by the pilot-motor system, two comparatively distinct systems of current-limit control are now in common use. In one of these is used a single relay, with series and shunt coils. In this system as each contactor closes it completes a momentary actuating circuit for the next contactor, which then closes and establishes a holding circuit for itself independent of the momentary circuit above mentioned. The momentary actuating circuit passes through

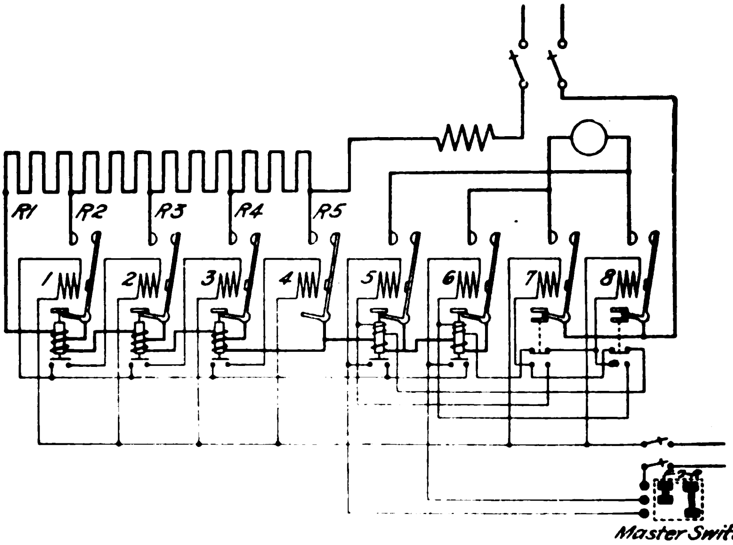

Fig. 3

the contacts and shunt coil of the relay and causes the iron core of the relay to lift an iron core into the field of influence of the series coil, thereby interrupting the circuit at the relay just after the contactor has completed its holding circuit. When the contactor is fully closed, the interlocks establish a circuit to the next contactor through the relay, so that the above operation will be repeated for this contactor in the same manner, provided the current in the series coil of the relay does not delay the completion of the circuit by holding the iron core up. In other words, if the increase of motor current caused by the closing of the contactor is great enough, the core of the relay will be held up and the " pickup " circuit for the next contactor will not be immediately completed. This system for reversible rheostatic control is shown in Fig. 1. The objection to this system is principally in the complicated interlocks necessary to perform the above operation. It has the advantage that the current-limit value for all of the contactors can be obtained by adjusting one relay. A further advantage lies in the considerable pressure with which the interlocks are held in contact. This advantage fits the system for use specially in transportation work and it is consequently most commonly used in railway service. A modification of this system using two relays and shown in Fig. 2, is an improvement in that less difficulty is met in adjusting the speed of the relays.

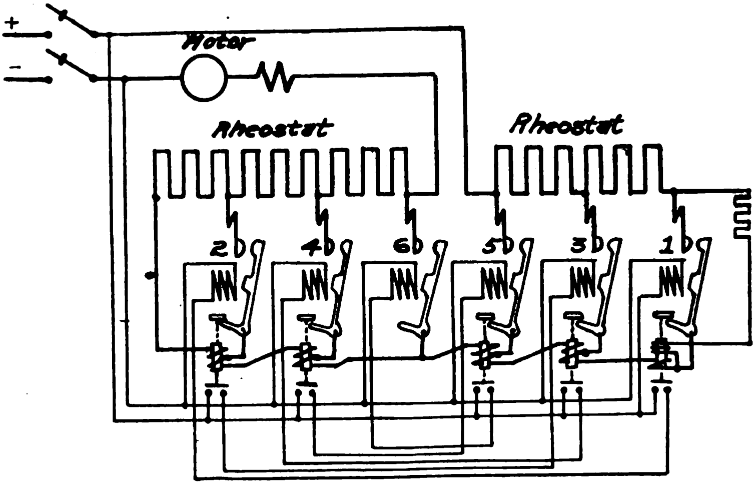

Fig. 4.—Current-limit control with separate relays arranged to introduce resistance into circuit step-by-step in case of overload

The second system makes use of a separate relay for each contactor. In its simplest form, each of the accelerating contactors includes as an integral part of itself an overload relay, which is held in the open position by a mechanical connection with the contactor until the contactor is closed, and is then allowed to drop and complete the circuit for the next contactor, only under the control of the current which passes through the contactor and the series coil of the relay. This arrangement is shown in Fig. 3, as used for a reversible control equipment.

A comparison of this system with the preceding ones will show its greater electrical simplicity. It will be seen that each series relay consists of two coils, and that these coils are so connected to the source of current and to the rheostats, that current flows through them both in series until the contactor is closed, after which current flows through only one coil. By this means, the relay is prevented from closing until the contactor has fully closed, and the increase of motor current resulting therefrom has become effective in the relay.

By using separate relays, acceleration can be secured at an increasing rate step by step or, if desired, at a decreasing rate. As ordinarily arranged, each relay is cut out of circuit as soon as the next contactor closes. In case, however, the circuits are so arranged that the relay is not cut out of circuit until the second next contactor closes, an equipment is obtained which has the interesting property of cutting resistance back into circuit step by step in case of an overload. The connections for accomplishing this result are shown in Fig. 4. Fig. 5 shows a motor starter with shunt type of relays in multiple with the starting resistance as described in the first part of this discussion.

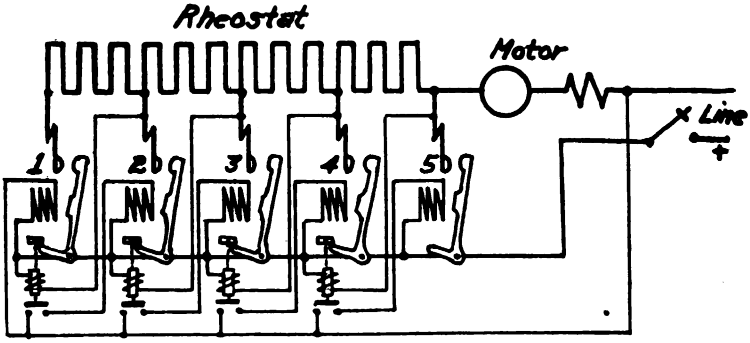

Fig. 5.—Automatic motor-starter with separate shunt-wound relays in multiple with starting resistance

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THE TESTING OF TRANSFORMER STEEL

BY M. G. LLOYD AND J. V. S. FISHER

Summary. The object of this paper is to discuss the conditions which should be realized in the measurement of energy losses in sheet-iron and steel subjected to alternating magnetization, with a description of a modification of the Epstein method and apparatus. This method is believed to better satisfy the desired conditions and to give an accuracy of one per cent with the use of less than two kilograms (4.4 lb.) of material.

Results are given showing a wide range in the quality of material in general use, quality having slight connection with price. Several foreign specimens of ordinary steel and silicon steel are included for comparison with the American product. Silicon steels contain from 3 to 4 per cent silicon, the quality not depending upon the exact percentage of silicon.

By making measurements at two frequencies, the eddy-current and hysteresis losses have been separated and a study made of the variation of each with flux density. The values of the hysteretic constant and the total loss in watts per pound at 60 cycles and 10,000 gausses are tabulated.

The effects of artificial aging are shown to depend upon the flux density selected for test, the hysteresis increasing more for 5000 than for 10000 gausses. Tests should therefore be made at the density to be used. The aging is usually negligible in silicon-steels.

Many methods have been employed for the testing of sheet-iron and steel for energy losses when subjected to alternating magnetization, but all that have so far been employed have been lacking in some desirable qualifications. The plotting of a hysteresis loop from readings of magnetizing force and the resulting magnetic induction, and the measurement of the area of this loop, is a slow and tedious process and gives no indication of the eddy-current losses. Methods depending upon the relative motion of the specimen and a magnet necessitate an air-gap in the magnetic circuit, with a resulting induction in the specimen which is far from uniform. Moreover, if a permanent magnet be used, as in the Ewing and the Blondel apparatus, one is restricted in the values of the flux density which may be used, and the apparatus is suitable only for comparative measurements at one flux density.

Consequently, methods of testing with alternating currents have come to be regarded as the only satisfactory way of making these measurements, and present efforts are directed to securing the best conditions for this form of test. In the wattmeter method, the electrical energy which is supplied to maintain the alternating magnetization is measured with a wattmeter, while the maximum magnetic induction produced in the specimen is determined by a voltage measurement at the terminals of the magnetizing winding or at the terminals of a secondary winding placed around the same core of test material.

The specimen may be employed in three forms: (1) It may be in the form of straight strips placed in contact with a yoke, thus forming a closed circuit of ferro-magnetic material. (2) The straight strips may be used without any yoke. (3) The specimen may be arranged to form a closed magnetic circuit in itself.

The second form gives a distribution of flux which is far from uniform, and is therefore objectionable. The first form gives a more uniform flux, but it is necessary to distinguish between the energy supplied to the specimen and that supplied to the yoke. This can be done satisfactorily only by knowing the constants of the yoke, and only then by having the distribution of flux uniform, a condition difficult to secure. Consequently, for accurate measurements the third form is the most reliable, although for factory use the first or second may prove more convenient where accuracy can be sacrificed for other considerations.

Assuming a closed magnetic circuit of the material to be tested by the wattmeter method, the following conditions should be realized as far as possible:

1. The flux should be uniformly distributed over the cross-section of the specimen, and should be the same at every section; this requires that there should be no leakage of flux through the air.

2. A definite form of wave of magnetic flux should be used, or in other words, a definite form of wave of secondary electromotive force, since the form-factor of this wave enters into the computation of maximum flux density from the observed effective voltage.

3. The material used should be cut in a form such that only a small part of it is contiguous to a cut edge, since it is well known that all methods of cutting have a hardening effect upon the material bordering upon the cut. This means that the strip, whether straight or in ring form, should not be too narrow. This condition may be dispensed with if all specimens are annealed under definite conditions after cutting to size and prior to testing.

4. The amount of material required should not be greater than is necessary to get a fair average value.

5. The corrections to be made in the readings of the instruments to obtain final values should be as few and as small as possible.

Two general forms of magnetic circuit are available. The material may be stamped into rings or the circuit may be built up from straight strips. Leakage is most effectually avoided by using rings. With this form of specimen, however, it is impossible to satisfy simultaneously conditions 1 and 3, unless rings of very great diameter are employed, and in the latter case there is a very great waste of material. The non-uniformity of flux existing in rings of small diameter, even when uniformly wound, and the errors resulting therefrom, have been discussed elsewhere.[1] The use of rings is thus restricted to cases where the material is annealed after stamping, and the radial width of the ring should be very small in comparison with its diameter. When rings are employed, the labor of winding each specimen separately with a magnetizing coil may be obviated by the use of the apparatus of Esterline[2] or Möllinger.[3]

To meet condition 2 it is sufficient to know or measure the form-factor of the secondary voltage.[4] By making runs at two frequencies it is then possible to separate the eddy-current and hysteresis losses, and, if desired, to compute the eddy-current loss for a standard wave-form.[5]

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[1] M. G. Lloyd, Bulletin of Bureau of Standards, 5, p. 435; 1909. *Electrical World* 52, p. 1395; 1908.

[2] J. W. Esterline, Proc. Am. Soc. Testing Materials 3, p. 288; 1903.

[3] J. A. Möllinger, Elektrot. Zs. 22, p. 379; 1901.

It is far preferable, however, to work throughout with a sine wave when a generator is available which will fulfill this condition. There are three things which may prevent the realization of this condition. In the first place the machine may not generate a sinusoidal electromotive force. In fact, it may be stated as a general proposition that no generator gives a perfect sine wave. The only question is as to the magnitude of the harmonics present, and whether these are negligible. It cannot be assumed that these are negligible simply because the machine was designed to give a sine wave, or because a rough oscillogram does not indicate definite distortion. The only way to be certain is to take an accurate curve from the machine and analyze it by measurement of the ordinates.

As an example of the necessity of this, we cite an instance occurring at the Bureau of Standards. Here the tests are usually made with a generator whose electromotive force wave contains a third harmonic whose amplitude is 0.6 per cent of the amplitude of the fundamental, and none of the higher harmonics are present to such an extent as 2 per cent. The form-factor is almost exactly that for a sine wave. One day a specimen, which had already been tested with this generator, was tested with a second generator supposed to give a sine wave whose oscillogram appeared smooth and inoffensive. The losses appeared more than 4 per cent lower than by the previous test. This led to a closer examination of the wave given by the generator, the wave being traced by the Rosa apparatus,[6] analyzed and found to contain nearly 7 per cent of the third harmonic, sufficient to account for the observed difference in losses.[7]

A second cause of distorted wave-form is to be found in armature reaction, which may alter the electromotive force of a loaded generator when the curve on no load is sinusoidal. For this reason, it is best in testing to use a machine so large that it is only slightly loaded by the test current.

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4. An apparatus for measuring form factor is described by Lloyd and Fisher, Bull. Bur. Stds. 4, p. 469; 1908.

5. See M. G. Lloyd, Bulletin Bureau of Standards 5, p. 381; 1909

6. See Rosa and Grover, Bulletin Bureau of Standards, 1, p. 138; 1905.

7. See M. G. Lloyd, Bulletin Bureau of Standards. 4, p. 484; 1908.

A third cause of distorted wave is to be found in the drop of potential due to the ohmic resistance of the circuit. The generator electromotive force is made up of two parts, one of which is balanced by the electromotive force induced by the changing flux, while the other produces current. If the flux be sinusoidal, the electromotive force induced by it is also sinusoidal. But owing to the fact that the permeability of the material varies with the magnetic induction, the magnetizing current cannot be sinusoidal. The component of the electromotive force producing current has the same form of wave as the current, and it also cannot be sinusoidal. The total electromotive force of the generator then, to produce sinusoidal flux, is made up of one component which is sinusoidal and one which is not, and therefore is not sinusoidal. Its shape must vary with varying conditions, and hence it would be useless to attempt to secure such a form of generator electromotive force. To approximate sinusoidal flux it is necessary to have a sinusoidal electromotive force at the generator and to make the component which sends current (equal to the product of current and resistance) negligible in comparison with the component which balances the electromotive force induced in the apparatus. It is desirable then to keep both resistance and current low in the magnetizing circuit. If this ohmic drop of potential can be made negligible, then the wave-form of flux will differ from a sine curve only by a negligible amount.

The resistance in the magnetizing circuit consists of the armature, leads, magnetizing coil, measuring instruments and perhaps of windings of transformers used to step up or down to the proper voltage. It should not include a regulating rheostat, but the current should be controlled through the generator field. Each of these items should be made as low as possible, and thus appears another reason for choosing a generator of capacity large in comparison to the load to be placed upon it. The magnetizing current may be kept low by having a magnetic circuit of low reluctance. Air-gaps should be avoided, and any joints in the magnetic circuit made as good as possible.

With the same magnetizing current, the induced electromotive force is proportional to the cross-section of test material; consequently the greater the quantity of material used, the less the distortion of the wave. With a definite cross-section and windings, the induced electromotive force is proportional to the maximum flux density, but the magnetizing current is not proportional to the flux density, owing to varying permeability. The larger the permeability, the larger the ratio of flux to magnetizing current. The distortion will consequently be less if the iron be magnetized in the region of maximum permeability, and the distortion is sure to become appreciable if the flux density be carried too high, and may become appreciable at very low flux densities, even when it is negligible through the range of working flux densities used industrially.

In the method of Epstein,[8] which has been adopted as standard in Germany,[9] these conditions are fairly well met. Ten kilograms of sheet are cut into strips 50 by 3 cm. and assembled into four bundles, over which solenoids are slipped. The four bundles are arranged in the form of a square, having butt joints at the corners, where the magnetic material is separated by a sheet of thick paper. This interruption to the magnetic circuit tends to make the flux more uniform across the section of test material, but it also makes the leakage greater, and the flux less equal at different sections. Thus the flux at the center of one bundle may exceed the flux near one end by as much as 8 per cent. This air-gap also increases the reluctance of the magnetic circuit, consequently increasing the magnetizing current, and a large quantity of test material must be used. Condition 4 is here sacrificed for the better attainment of conditions 1, 2, and 3, and yet conditions 1 and 3 are not very well satisfied.

A modification of this method has been developed at the Bureau of Standards differing from the foregoing principally in the arrangement of the test material. A smaller quantity of material in wider strips may be used, while at the same time a greater uniformity of flux is secured. The amount of material used is from 1.5 to 2 kg. (less than 4 lbs.), and an accuracy of one per cent is attained

Description of the Apparatus

The specimen to be tested is cut into strips 25.4 by 5 cm. (10 by 2 inches). These are assembled into four bundles, in each of which adjacent strips are separated by strips of press board of equal width and thickness, but 2 cm. shorter. Each bundle is wrapped with friction tape and is inserted in a solenoid.

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[8] I. Epstein, Elektrotechnische Zeitschrift 21, p. 303; 1900.

[9] Elektrot. Zs. 24, pp. 657, 684; 1903.

The four bundles are then arranged in a square so that the plan view shows the edges of the strips, as in Fig. 1. The solenoids are wound upon fiber frames 22.7 cm. long, and have inside dimensions 5 cm. by 1 cm. At the corners of the square, short pieces of test material are bent at right angles and interleaved between the strips of adjacent bundles, as shown in the figure. There are as many of these corner pieces as there are test pieces, and they are graduated in length so as to give a uniform lap of about 2 mm. A special clamp, shown in Fig. 2, is tightened over these laps, so as to give a good magnetic joint.

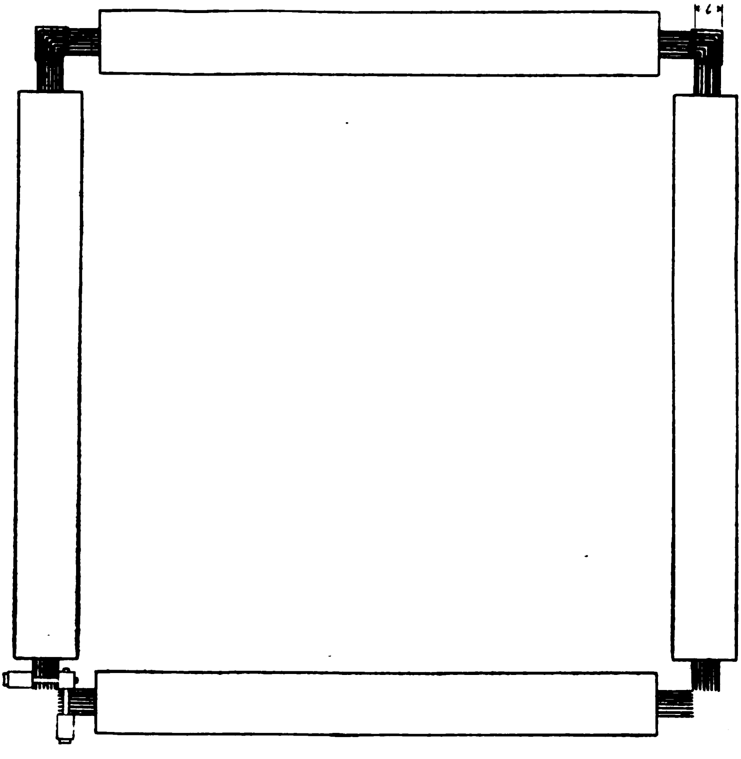

Fig. 1.—Plan of apparatus, showing corner pieces in place at two corners and clamp in place at one corner

Each solenoid has in its first layer two windings of double-silk-covered No. 20 wire, each consisting of 45 turns. Over these are wound 250 turns of No. 14 copper wire, also double-silk-covered, to form a magnetizing coil. The four solenoids are connected in series, making a total of 1000 magnetizing turns and two secondaries of 180 turns each. One of these secondaries is connected to a voltmeter for determining the magnetic flux. This instrument is a deflecting mirror dynamometer, giving a sufficient deflection with 0.004 ampere. The other secondary is connected to the moving-coil circuit of a watt dynamometer of the same type as the voltmeter. The magnetizing current traverses the field coils of this wattmeter, whose deflections are a measure of the power supplied to the core and the secondary coils. The copper loss in the primary is thus eliminated from the power measurement,[10] as is evident from the following considerations.

Let N_1 = primary turns.
N_2 = secondary turns.
Φ = flux threading both primary and secondary.
i = primary or magnetizing current.
e = electromotive force applied to primary.
L = self-inductance of primary due to any flux not included in Φ.

Then

$$e - N_1 \frac{d\,\Phi}{d\,t} - L\,\frac{d\,i}{d\,t} = ri$$

The instantaneous power expended is

$$e\,i = r\,i^2 + N_1\,i\,\frac{d\,\Phi}{d\,t} + L\,i\,\frac{di}{d\,t}$$

The integral of this expression, extended over a complete cycle, will give the net power. The term $r\,i^2$ represents the primary copper loss. The term $L\,i\,\frac{d\,i}{d\,t}$ when integrated over a complete cycle, is equal to zero. The term $N_1\,i\,\frac{d\,\Phi}{d\,t}$ will not integrate to zero when there is either hysteresis in the core or secondary currents (including eddy currents) are flowing, since in either case Φ is not in phase with i. This term represents the power expended in the core and in the secondary circuits. $N_2\,i\,\frac{d\,\Phi}{d\,t}$ is proportional to this, and its integral value represents the reading of the wattmeter when connected as in this apparatus. Hence the wattmeter reading, when multiplied by $\frac{N_1}{N_2}$, gives the power expended in the core and in the secondary circuits. Error will arise only when there is flux threading the core and linked with the primary, which is not linked with the secondary. This is avoided by winding the secondary under the primary, and making the two coextensive in length. The energy in each secondary is obtained by squaring the secondary voltage and dividing by the resistance of its circuit. By using a low number of turns in the secondaries and sensitive instruments, these corrections are kept very small and are accurately known.

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[10] Due to C. P. Steinmetz, Trans. A.I.E.E., Vol. IX, p. 624; 1892.

The voltmeter and the wattmeter each have variable multipliers, whose resistance is adjusted to give a suitable deflection in each case. The accuracy of reading is usually better than 0.1 per cent, and is higher than the conditions require.

The frequency is determined by a Hartmann and Braun frequency meter, which has been calibrated by the use of a chronograph, or where greatest accuracy is required the chronograph is read directly.[11]

When it is desired to measure the exciting current, an ammeter can be introduced into this circuit, but the exciting current for ordinary inductions is so low that it is difficult to secure an ammeter of sufficiently low resistance. The only type of portable instrument which has served this purpose is the Duddell thermo-ammeter. This can be obtained with a range of 0.5 ampere and a resistance of 0.2 ohm.

The use of corner pieces bent at right angles caused at first some apprehension as to its effect upon the results. It is known that bending, like any other mechanical treatment, will change the magnetic properties of the steel. If this affects enough of the steel seriously to alter the average value, it would condemn the method. Experiments which were directed to the determination of this effect showed that it is of no importance. The corner pieces are bent sharply in a machine which distorts the material to only a very short distance from the angle. The distorted material has its constants considerably changed without doubt, but as the corner pieces constitute only about 5 per cent of the entire circuit, and as only a part, say 30 per cent, of this material is altered by a fraction, say 20 per cent, of its initial value, an error of much less than 1 per cent is made by regarding this material as unaffected by the bending, and 1 per cent is the limit of accuracy claimed for the method.

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[11] This use of the chronograph, with specimen record, is described by M. G. Lloyd, Bulletin Bureau of Standards, 5, p. 388; 1909.

To examine experimentally the effect of bending, a measurement was made in the usual way; the strips were then removed and each was bent at right angles and then bent straight at a point close to the first bend, so that the length was only slightly altered. A new measurement showed that the losses had increased by 1 per cent. A single bend would of course affect them by much less than this. Another experiment consisted in making measurements upon annealed specimens, and others not annealed, each with corner pieces of its own material. The corner pieces not annealed were then used with annealed test pieces, and after making the proper corrections and allowances for loss in the corner pieces, as described later, the values for the test pieces were found in agreement with those previously obtained with annealed corner pieces. As the annealed material is very much more sensitive to mechanical treatment than that not annealed, the effect must have caused different results in the two cases if it were operative to more than a negligible degree. A third method of checking this point was tried, and led to the same conclusions, but the foregoing are considered sufficient evidence.

On account of the lapping of the corner pieces over the ends of the test pieces, the flux density is low in this part of the material, necessitating a correction in the results. The amount of lap is determined by the relative weights of corner and test pieces, as compared with the relative lengths of the two parts of the circuit. When the corner pieces are of the same material as the test pieces, it is assumed that the flux density is halved in the portion of material which laps, and the energy loss is consequently only one-third normal.

B = nominal, or average, maximum flux density.
B_1 = maximum flux density at ends of test pieces.
M = mass of test pieces.
m = mass of corner pieces.
l = dimension shown in Fig. 1.
W = measured loss.
$\frac{m}{M}$ = proportional increase in mass of magnetic circuit, due to corner pieces,

$\frac{l}{25.4}$ = proportional increase in length of magnetic circuit, due to corner pieces.

$\frac{m}{M} - \frac{l}{25.4} = c$ = mass of corner pieces which lap, expressed in terms of mass of test pieces.

$2c$ = total material (lapped and lapping steel) in which flux density is $\frac{B_1}{2}$

$$2\,c\,W\left[1-\left(\frac{B_1}{2\,B}\right)^x\right] = 2\,c\,W\,k = \text{correction to } W \text{ for lap,}$$

where x expresses the law of variation of loss with B. k varies slightly with the conditions. If $B_1 = B$ (no leakage)

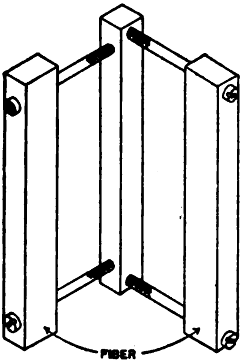

FIG. 2

and $x = 1.6$, $k = 0.67$. For $x = 2.0$ this becomes 0.70. For 4 per cent leakage, $x = 1.6$, $k = 0.68$. With sufficient accuracy for the purpose k may be taken as 0.70 throughout, so that the correction becomes $1.4\ c\,W$ and the loss per unit mass is

$$\frac{W}{M+m}(1+1.4\,c) \text{ or } \frac{W}{(M+m)\ (1-1.4\,c)}$$ with sufficient accuracy. The latter form is the most useful in practice, since a number of observations at different flux densities are usually made upon a single specimen, and the correction may be made once for all to the mass. The quantity $(M+m)\ (1-1.4\,c)$ may be called the "effective mass."

At first, a set of corner pieces was made for each set of test pieces of the same material, but this has been found unnecessary.

Corner pieces of approximately the same quality and thickness may be used with satisfactory and reliable results, provided the constants of the material are known. The Bureau of Standards has now accumulated a sufficient variety of corner pieces so that it is seldom necessary to make a new set, unless unusual precautions are to be taken. When using corner pieces of different material from the test pieces, it is necessary to compute the loss in the entire corner pieces, and then determine an "effective mass" resulting from the lap reducing the flux in the test pieces, Since the thickness of corner pieces may be different from that of the test pieces, it is necessary to consider this fact, and the flux at the lap may be considered to divide evenly between the two, or in proportion to their thickness. As the results do not differ materially, we assume that in each lapped part the flux density is half the value in the rest of the material.

Let

t = thickness of test pieces.
t_1 = thickness of corner pieces.
w = loss per unit mass in corner pieces.

and other quantities as before. We neglect the leakage, which is small. c must now be computed by using for M the mass M_1 of test pieces of the same material as the corner pieces. The loss in the corner pieces, if there were no lap, would be $w\,m\left(\frac{t}{t_1}\right)^x$.

Considering the effect of lap the loss is $w\,(m-0.7\,c\,M_1)\left(\frac{t}{t_1}\right)^x = W_c$. The correction applied to the loss in test pieces due to lap is $0.7\,c\,(W-W_c)$ and the loss per unit mass is $\frac{W-W_c}{M\,(1-0.7\,c)}$.

If the corner pieces are of the same thickness as the test pieces, the loss in them becomes $w\,(m-0.7\,c\,M_1)$, and this expression will usually give the correction closely enough. Here again the quantity $(m-0.7\,c\,M_1)$ can be determined once for an entire set of measurements.

If the flux at the lap be assumed to divide between the two in proportion to thickness, we have for the loss in the corner pieces

$$w\left[\,(m-c\,M_1)\left(\frac{t}{t_1}\right)^x+c\,M_1\left(\frac{t}{t+t_1}\right)^x\right]$$

and the correction for lap in the test pieces is

$$c\,(W - W_c)\left[1 - \left(\frac{t}{t+t_1}\right)^x\right]$$

The leakage with this arrangement of test material, that is, the difference between flux at the ends of test piece and at the middle, is usually not greater than one per cent. Since the greatest length of a line of induction is 8 per cent larger than the least, there is a probability of the same difference in flux density between the outer and inner sheets As the average flux density is measured, this cannot make an error greater than a small fraction of one per cent.[12] Inequality in the four arms has an equally slight effect. Upon removing one sheet in 12 from opposite sides, the loss per unit mass was not appreciably altered.

OBSERVATIONS AND RESULTS

The procedure in making a test is as follows: The material is cut into strips of the given dimensions by the use of a sharp machine shear with nearly parallel jaws. The number of strips is determined by the thickness, and for gage No. 29 amounts to 48. The strips are then weighed, bundled and mounted in the solenoids. The effective voltage corresponding to any given flux density and frequency is computed from the following relation.

$$E = 4 f N n \Phi\, 10^{-8} = \frac{4.44 \times 180 \times 10^{-8}\, B\, n\, M}{101.6\, \rho}$$

where n = frequency, Φ = total flux, f = form-factor of the secondary electromotive force, and ρ = density. In the work here reported ρ has been taken as 7.77 grams per cubic centimeter, but it is proposed hereafter to determine the density for each specimen.

The dynamometer voltmeter is calibrated for one voltage as determined above, and when taking observations for watt loss, the generator voltage is adjusted until the same deflection is obtained. For other frequencies and flux densities, the resistance in the voltmeter circuit is altered until it is proportional to the product $B\, n$, so that the same deflection is always used. For the lower values of this resistance, the slight correction due to the inductance of the instrument is also made. In computing the power supplied to the voltmeter circuit, it may then be remembered that this energy is also proportional to $B\,n$, since the same current is used throughout. A similar series of resistances is usually used in the potential circuit of the wattmeter, so that the power consumed here is also readily computed. The deflection, however, will increase as the product $B\,n$ increases, but will usually remain within working limits of permissible deflections. These limits are so chosen that within them the deflections are proportional to the watts. The multipliers for the potential circuit are so chosen that for one of them the actual watts corresponding to a given deflection, when multiplied by $\frac{N_1}{N_2} = \frac{1000}{180}$, are numerically equal to the deflection. The wattmeter is then direct-reading for this range for the values of the watts required, and for other ranges a simple factor determined by the value of $B\,n$ gives the desired result.

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[12] See M. G. Lloyd, Bulletin Bureau of Standards, 5, p. 435; 1909.

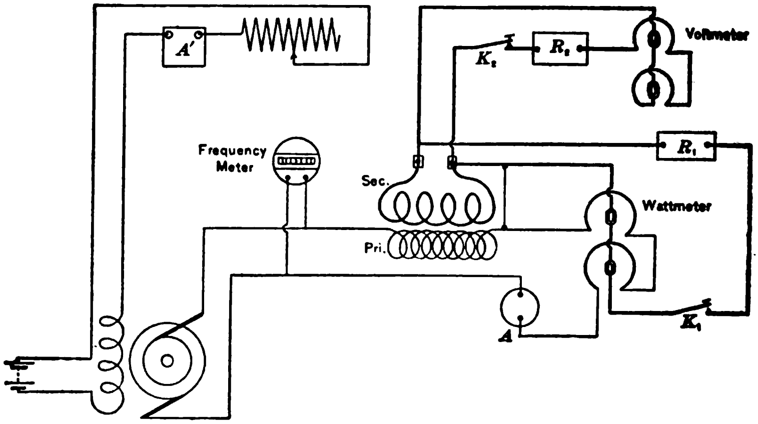

FIG. 3.—Diagram of connections

The generator used gives an electromotive force wave which is sufficiently close to the sinusoidal, and the form-factor of the secondary electromotive force has been determined and found sufficiently near to that assumed through the working ranges of flux density at the frequencies used, which usually are 60 and 30 cycles, the latter being chosen because it makes the separation of hysteresis and eddy-current losses easy to compute. The generator is driven by an electric motor whose field circuit contains a rheostat in the laboratory, permitting adjustment of speed for a definite frequency. The motor is supplied with power from a storage battery so that a steady speed may be maintained. The field circuit of the generator is connected through another rheostat in the laboratory, which permits adjustment of the generator voltage to give the flux density desired. No rheostat is used in the magnetizing circuit. When necessary, a transformer of ample capacity is used to step up or down to the voltage required for the test.

The electrical connections are shown in Fig. 3, where for simplicity a single secondary is represented, which may indeed be used in practice. When the generator voltage has been adjusted to give the proper reading on the voltmeter connected to the secondary circuit, the wattmeter is read. These settings are repeated twice. An adjustment is then made for a different flux density and readings are taken as before. When the exciting current is desired, an ammeter is included in the magnetizing circuit, and its indications noted. Whenever a change is made from a higher to a lower flux, the current is reduced gradually to the lower value in order to demagnetize the material. This descending set of observations is usually made at a frequency of 30 cycles. Whenever the magnetizing circuit has been broken, it is closed through a considerable resistance, which is continuously reduced to zero in order to prevent a large first surge and consequent high magnetization, which would require subsequent demagnetization.

TABLE I.
SPECIMEN K
TEST PIECES = 1327 GRAMS. CORNER PIECES = 80.2 GRAMS. $c = 0.029$.
EFFECTIVE MASS = 1350 GRAMS

Cycles	Flux density	Wattmeter deflection	Watts	Instrument losses	Iron losses	Joules per cycle	Ergs per gram per cycle	Hysteresis	Eddy currents
60	10000	21.38	4.276	0.079	4.197	0.0699	518	394	124
30	10000	18.87	1.887	0.0395	1.848	0.0616	456	394	62
60	5000	13.54	1.354	0.0395	1.314	0.0219	162	130	32
30	5000	12.20	0.610	0.0197	0.590	0.0197	146	130	16

Table I gives a specimen set of observations where the corner pieces were of the same material, while in Table II they were of different material.

The total loss is separated into two components, due respectively to hysteresis and eddy currents, as follows, using the Steinmetz equation,

$$W = \eta\, n\, B^x + \zeta\, n^2\, B^y$$

where the symbols have the same significance as before, η and ζ being constants of the material. By taking observations at two frequencies, n_1 and n_2 we have

$$\frac{W_1}{n_1} = \eta\, B^x + \zeta\, n_1\, B^y = a + b\, n_1$$

TABLE II

SPECIMEN H_1

TEST PIECES = 1304 GRAMS. CORNER PIECES OF SPECIMEN K = 80.2 GRAMS. c = 0.029. EFFECTIVE MASS = 1278 GRAMS

Cycles	Flux density	Watt-meter deflection	Watts	Instrument losses	Iron losses	Joules per cycle	Corner pieces	Test pieces	Ergs per gram per cycle
60	10000	21.55	4.310	0.076	4.234	0.0706	0.0028	0.0678	531
30	10000	18.95	1.895	0.038	1.857	0.0619	0.0024	0.0595	465
60	5000	13.74	1.374	0.038	1.336	0.0223	0.0009	0.0214	168
30	5000	12.34	0.617	0.019	0.598	0.0199	0.0008	0.0191	150

$$\frac{W_2}{n_2} = \eta\, B^x + \zeta\, n_2\, B^y = a + b\, n_2$$

where a is the hysteresis loss per cycle and $b\, n$ the eddy-current loss per cycle.

$$a = \frac{\dfrac{W_2}{n_2}\, n_1 - \dfrac{W_1}{n_1}\, n_2}{n_1 - n_2}$$

$$b = \frac{\dfrac{W_1}{n_1} - \dfrac{W_2}{n_2}}{n_1 - n_2}$$

If $n_1 = 2\,n_2$ this computation is greatly simplified; for then

$$b\,n_2 = \frac{W_1}{n_1} - \frac{W_2}{n_2}$$

$$b\,n_1 = 2\,b\,n_2$$

$$a = 2\,\frac{W_2}{n_2} - \frac{W_1}{n_1} = \frac{W_2}{n_2} - b\,n_2$$

While the Steinmetz equation, and consequently this separation, is not accurately in accordance with the facts, the errors are very small in thin sheets. The exponents x and y can be determined by observations at different flux densities, and these have been computed for a number of specimens, as shown in Tables III to VII. Where the eddy-current loss is small, as in silicon steel, the values of y are subject to greater error.

TABLE III

VARIATION OF EXPONENTS WITH FLUX DENSITY

SPECIMEN P_1

Cycles	B	Loss per cycle	Hysteresis	Eddy currents	Exponents	
					Hysteresis	Eddy currents
60	12000	842.7	445.7	397.0		
30	12000	644.2	445.7	198.5	2.12	2.03
60	10000	576.8	302.8	274.0		
30	10000	439.8	302.8	137.0	1.75	1.97
60	8000	381.4	204.8	176.6		
30	8000	293.1	204.8	88.3	1.68	1.83
60	6000	230.9	126.5	104.4		
30	6000	178.7	126.5	52.2	1.53	1.97
60	4000	114.9	67.9	47.0		
30	4000	91.4	67.9	23.5	1.51	2.03
60	2000	35.4	23.8	11.6		
30	2000	29.6	23.8	5.8		

While these exponents do not exhibit any definite and constant value, it will be noticed that the hysteresis exponent does not differ much from 1.6 for flux densities between 5000 and 10000 gausses, while for densities exceeding 10,000 it is in the neighborhood of 2, with a definite tendency upward. The exponents for eddy-current loss vary rather widely from 2 in some instances, but with specimen *C* in Table VII, where the eddy-current loss is greater and the results consequently more accurate, the values come close to 2.

In order to test the proportionality between eddy-current loss and frequency, some runs were made with a second generator which gave 180 cycles at normal speed and 90 cycles at half speed. The wave-form of this generator is not so pure as that of the one used for the lower frequencies, but the loss could be altered by less than two per cent at most from this cause, and probably not over one per cent. The error from this cause would be less at 180 cycles than at 90 cycles. The measured loss, however, is a great deal lower at 180 cycles than is computed from the results at 30 and 60 cycles. This is illustrated by the experiments exhibited in Table VIII, where the hysteresis and eddy-current losses are separated by use of the readings at 30 and 60 cycles. The hysteresis is assumed constant, and the resulting eddy-current loss does not increase as rapidly as the frequency. The eddy-current loss falls off more rapidly, the thicker the specimen. The effect is greatly accentuated in specimen *A*, which consists of sheets 1.6 mm. thick, and was tested by using butt joints at the corners of the apparatus. The results of specimen *P* are plotted in the curve of Fig. 4. The

TABLE IV

VARIATION OF EXPONENTS WITH FLUX DENSITY

SPECIMEN *K*

Cycles	Flux density	Loss per cycle	Hysteresis	Eddy currents	Exponents	
					Hysteresis	Eddy currents
60	12500	820	638	182		
30	12500	729	638	91	2.16	1.7
60	10000	518	394	124		
30	10000	456	394	62	1.71	1.9
60	7500	313	241	72		
30	7500	277	241	36	1.53	1.9
60	5000	162.2	129.2	33		
30	5000	145.7	129.2	16.5	1.47	2.0
60	2500	54.6	46.6	8.0		
30	2500	50.6	46.6	4.0		

TABLE V
VARIATION OF EXPONENTS WITH FLUX DENSITY
SPECIMEN W_1

Cycles	Flux density	Loss per cycle	Hysteresis	Eddy currents	Exponents	
					Hysteresis	Eddy currents
60	12500	379	309	70.		
30	12500	344	309	35.	2.04	2.0
60	10000	241	196	45.		
30	10000	218.5	196	22.5	1.68	1.9
60	7500	146.8	120.8	26.0		
30	7500	133.8	120.8	13.0	1.60	2.0
60	5000	74.7	63.1	11.6		
30	5000	68.9	63.1	5.8	1.59	2.2
60	2500	23.6	21.0	2.6		
30	2500	22.3	21.0	1.3		

TABLE VI
VARIATION OF EXPONENTS WITH FLUX DENSITY
SPECIMEN *R*

Cycles	Flux density	Loss per cycle	Hysteresis	Eddy currents	Exponents	
					Hysteresis	Eddy currents
60	14000	606	524	82		
30	14000	565	524	41	1.88	1.6
60	12000	456	392	64		
30	12000	424	392	32	1.71	2.1
60	10000	331	287	44		
30	10000	309	287	22	1.68	1.7
60	8000	227	197	30		
30	8000	212	197	15	1.58	2.2
60	6000	141	125	16		
30	6000	133	125	8	1.65	1.65
60	4000	72.2	64	8.2		
30	4000	68.1	64	4.1	1.69	1.8
60	2000	22.1	19.7	2.4		
30	2000	20.9	19.7	1.2		

intercept of this curve upon the vertical axis represents the hysteresis loss. A dotted straight line has been drawn through the points for 30 and 60 cycles. We cannot be far wrong in assuming that the curve coincides with this at low frequencies, and consequently the method used for the separation of hysteresis and eddy-current losses is justified for thin sheets.

The falling off of the eddy-current loss at higher frequencies is explained by the consideration that the magnetizing force of the eddy currents reduces the flux in the center and crowds it towards the surfaces of the specimen; the short eddy-current paths enclose a smaller flux, while the longest still enclose the same; hence the average electromotive force of the eddy circuits does not increase as fast as the frequency.

TABLE VII
VARIATION OF EXPONENTS WITH FLUX DENSITY
SPECIMEN *C*

Cycles	Flux density	Loss per cycle	Hysteresis	Eddy currents	Exponents	
					Hysteresis	Eddy currents
60	13000	0.3554	0.2872	0.0682		
30	13000	0.3213	0.2872	0.0341	1.82	1.96
60	11000	0.2611	0.2119	0.0492		
30	11000	0.2365	0.2119	0.0246	1.59	2.00
60	9000	0.1868	0.1540	0.0328		
30	9000	0.1704	0.1540	0.0164	1.53	1.98
60	7000	0.1247	0.1047	0.0200		
30	7000	0.1147	0.1047	0.0100	1.48	1.93
60	5000	0.0741	0.0637	0.0104		
30	5000	0.0689	0.0637	0.0052	1.43	1.96
60	3000	0.0345	0.0307	0.0038		
30	3000	0.0326	0.0307	0.0019		

Some experiments were made with thick copper sheets in a solenoid. On account of the low flux densities secured, small quantities of energy had to be measured and the accuracy was not high, but the results indicated that the eddy-current loss did not increase as rapidly as n^2, but somewhat more rapidly than B^2. The latter result is, however, somewhat doubtful.

By taking readings upon an ammeter in the magnetizing circuit, it is possible to compute the wattless component of exciting current, and a curve of such values is plotted in Fig. 5 in relation to the flux density. Such a curve is just as valuable to the designer, or perhaps more valuable, than a magnetization curve obtained by the ballistic method. A similar curve for silicon steel is plotted in the same figure. A ballistic curve which has been obtained by Dr. C. W. Burrows for a sample of silicon steel from the same source, but from a different lot, is also shown but to a different scale. The low magnetizing current required by silicon steel at low flux densities makes it particularly suitable for current transformers which must have close regulation, as when used with measuring instruments.

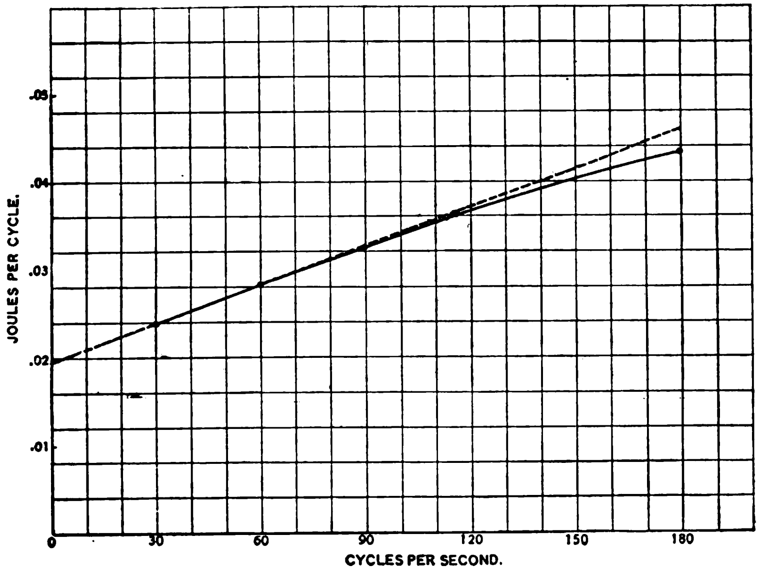

Fig. 4.—Transformer sheet No. 27 gauge at 5000 gausses

That the hysteresis loss is larger when the steel is magnetized normal to the direction of rolling, than when magnetized parallel to the direction of rolling, is shown by Table IX and the curves of Fig. 6. The eddy-current loss in the two cases is practically the same, but the hysteresis is 5 to 10 per cent higher for magnetization normal to the direction of rolling. This specimen is basic open-hearth steel, but the fact is typical of steel from all sources, though the magnitude of the effect is very variable. Table X shows a similar test upon steel from another source.

The authors have made tests of sheet-iron and steel from a great variety of sources, and have been surprised at the great range in quality of the material in general use by electrical manufacturers, the quality usually having no close relation to the price. Table XI shows some of the results obtained, all the materials having been secured from electrical manufacturers, or from iron mills and dealers supplying the electrical trade. Some foreign samples have been included in the table for comparison. The values of η have been computed from the relation $\frac{W}{n} = \eta B^{1.6}$; where $\frac{W}{n}$ is the hysteresis loss in ergs per cubic centimeter per cycle at 10,000 gausses.

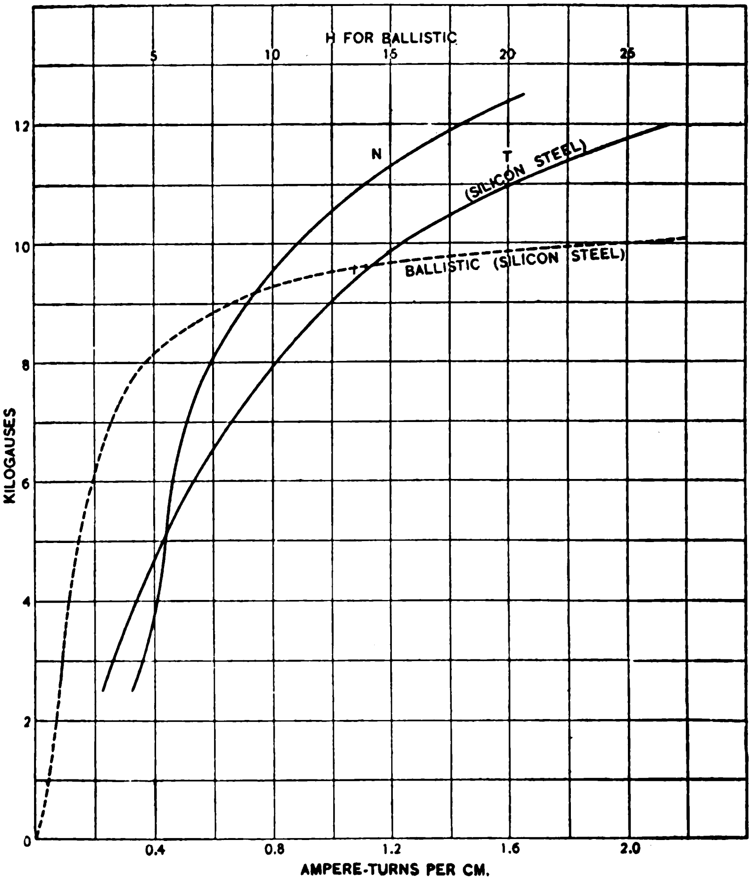

FIG. 5.—Magnetization curves

The adjustments can be made and the readings taken so quickly after the circuit is closed, that the specimen becomes heated appreciably only when it is of poor quality or when extremely high frequencies or flux densities are used. The results consequently apply to room temperature. This varies from time to time through several degrees, but it has not been thought necessary to give the temperature in each case. The hysteresis varies only slowly with the temperature, and the eddy-current loss, which varies more rapidly, is the smaller part of the total, especially with silicon steel.

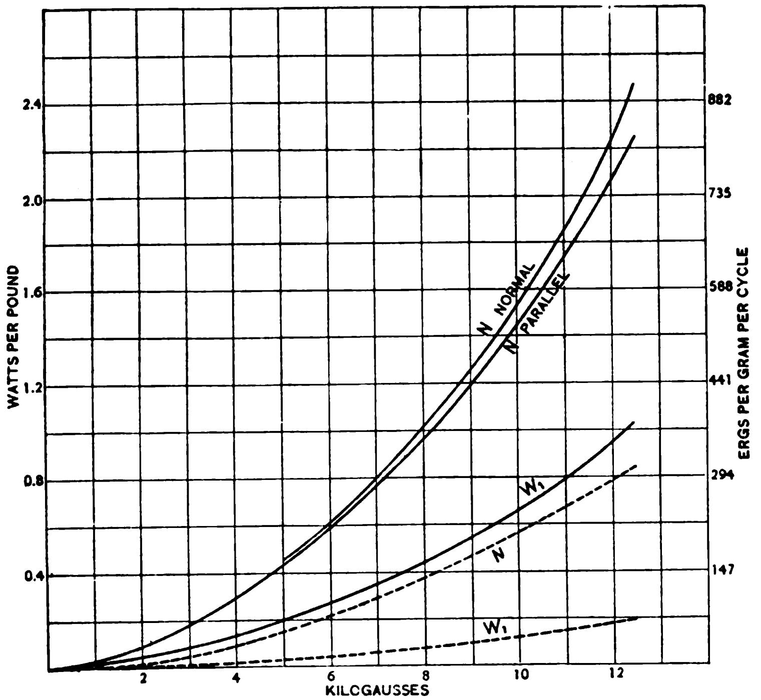

FIG. 6.—Relation between flux density and losses at 60 cycles when magnetized parallel and normal to direction of rolling. Solid lines represent total loss dotted lines eddy-current loss, difference is due to hysteresis. N = ordinary steel; W = silicon steel

Specimens P and P_1 should perhaps be classed as silicon steels, although their silicon is not in the proportion which is typical of the alloy. Moreover, they are not put upon the market as an alloy steel, but are sold at about the price of

TABLE VIII

VARIATION OF EDDY-CURRENT LOSS WITH FREQUENCY

SPECIMEN *C*. $B = 5000$ GAUSSES. THICKNESS = 0.0422 cm.

Cycles	Joules per cycle	Hysteresis	Eddy currents observed	Eddy currents computed	Difference per cent
30	0.06844	0.06221	0.00623		
60	0.07467	0.06221	0.01246		
90	0.08074	0.06221	0.01853	0.01869	0.9
180	0.09626	0.06221	0.03405	0.03738	9.8

SPECIMEN *P*. $B = 5000$ GAUSSES. THICKNESS = 0.0437 cm.

Cycles	Joules per cycle	Hysteresis	Eddy currents observed	Eddy currents computed	Difference per cent
30	0.02385	0.01944	0.00441		
60	0.02826	0.01944	0.00882		
90	0.03249	0.01944	0.01305	0.01323	1.5
180	0.04329	0.01944	0.02385	0.02646	11.0

SPECIMEN A_1. $B = 3000$ GAUSSES. THICKNESS = 0.16 cm.

Cycles	Joules per cycle	Hysteresis	Eddy currents observed	Eddy currents computed	Difference per cent
30	0.0781	0.0510	0.0271		
60	0.1052	0.0510	0.0542		
90	0.1263	0.0510	0.0753	0.0813	7.4
180	0.1765	0.0510	0.1255	0.1626	22.8

TABLE IX

SPECIMEN *N*

MAGNETIZED PARALLEL TO DIRECTION OF ROLLING

Cycles	Flux density	Ergs per gram per cycle	Hysteresis	Eddy currents
60	10000	531	321	210
30	10000	426	321	105
60	7500	318	196	122
30	7500	257	196	61
60	5000	161	105	56
30	5000	133	105	28

MAGNETIZED NORMAL TO DIRECTION OF ROLLING

Cycles	Flux density	Ergs per gram per cycle	Hysteresis	Eddy currents
60	10000	562	352	210
30	10000	457	352	105
60	7500	332	208	124
30	7500	270	208	62
60	5000	167	110	57
30	5000	138.5	110	28.5

ordinary steel; hence they are classified as such. None of the samples analyzed showed more than the slightest trace of vanadium. Specimen Q contained 0.3 per cent of aluminum. For the chemical analyses we are indebted to Dr. H. C. P. Weber and Mr. J. R. Cain, of the Bureau of Standards.

Artificial aging has been practiced upon a number of the specimens, and consists in baking in an oven whose temperature is kept between 90 degrees and 100 degrees cent. The baking is interrupted only for the purpose of taking observations, which is done after the specimen has cooled to the room temperature.

TABLE X

SPECIMEN P_1

MAGNETIZED PARALLEL TO DIRECTION OF ROLLING

Cycles	Flux density	Ergs per gram per cycle	Hysteresis	Eddy currents
60	10000	576	302	274
30	10000	439	302	137
60	5000	168	96	72
30	5000	132	96	36

MAGNETIZED NORMAL TO DIRECTION OF ROLLING

Cycles	Flux density	Ergs per gram per cycle	Hysteresis	Eddy currents
60	10000	608	336	272
30	10000	472	336	136
60	5000	175	103	72
30	5000	139	103	36

The results are shown in Table XII, where the per cent change in total loss is given after various periods of aging. The time given is only approximate. The silicon steels are almost entirely free from aging, but all the other specimens tested aged considerably, except L_1, and the test upon this was not continued for a very long period.

Caution must be exercised in applying the results of such tests, as one may be easily misled by them. Thus the hysteresis and eddy-current losses may be differently affected and, moreover, the hysteresis at different flux densities may be differently

TABLE XI

Designation	Thickness	Ergs per gram per cycle							
		10000 gausses				5000 gausses			
		60 cycles	30 cycles	Hysteresis	Eddy currents at 60~	60 cycles	30 cycles	Hysteresis	Eddy currents at 60~
Not annealed	cm								
A	0.0399	1785	1692	1599	186	608	585	562	46
B	0.0326	1290	1223	1156	134	420	402	384	36
C	0.0422	1274	1153	1032	242	426	391	356	70
D	0.0381	1193	1101	1009	184	401	377	353	48
Annealed									
E	0.0476	971	853	735	236	304	275	246	58
F	0.0280	766	716	666	100	247	233.5	220	27
G	0.0394	773	668	563	210	247	220	193	54
*H	0.0307	558	485	412	146	177.5	158	138.5	39
*H_1	0.0277	531	465	399	132	168	150	132	36
J	0.0318	543	442	341	202	166.5	139	111.5	55
*K	0.0282	518	456	394	124	162	146	130	32
*K_1	0.0280	541	479	417	124	170	152	134	36
†L	0.0346	565	473	381	184	175	150	125	50
†L_1	0.0366	615	516	417	198	192	165	138	54
B_1	0.0338	554	454	354	200	173	144.5	116	57
M	0.0335	550	461	372	178	173	150	127	46
N	0.0340	531	426	321	210	161	133	105	56
N_1	0.0312	523	435	347	176	162.5	137.5	112.5	50
P	0.0437	518	426	334	184	157	132	107	50
P_1	0.0470	576	439	302	274	168	132	96	72
Silicon steels									
†Q	0.0361	357	330	303	54	113	105.5	98	15
†Q_1	0.0366	390	360	330	60	124	117	110	14
R	0.0315	330	309	288	42	104	98.5	93	11
S	0.0452	350	314	278	72	108	99	90	18
T	0.0338	310	280	250	60	96	87	78	18
U	0.0346	312	291	270	42	98	92	86	12
U_1	0.0325	322	300	278	44	101	94	87	14
*V	0.0310	298.5	275	251.5	47	92	85.5	79	13
*V_1	0.0297	303	280	257	46	93	87	81	12
*W	0.0305	240	218.5	197	43	74.7	68.5	62.3	12.4
*W_1	0.0311	241	218.5	196	45	74.7	68.9	63.1	11.6
X	0.0430	265	232.5	200	65	80.8	72.5	64.2	16.6

* German.
† English.
NOTE.—In order to make a fair comparison the eddy-current loss has been computed for a thickness of 0.0357 cm. (gauge No. 29), assuming the loss proportional to the square of the thickness.

TABLE XI.—Continued.

					Watts per pound at 60 cycles and 10000 gausses		
Designation	x	y	η	Per cent silicon	Eddy currents loss for gauge No. 29 see note	Hysteresis	Total
Not annealed							
A	1.51	2.02	0.0049		0.41	4.35	**4.76**
B	1.59	1.89	0.00358		0.44	3.14	**3.58**
C	1.51	1.79	0.00319		0.47	2.81	**3.28**
D	1.52	1.94	0.00312		0.44	2.74	**3.18**
Annealed							
E	1.58	2.02	0.00227		0.36	2.00	**2.36**
F	1.60	1.88	0.00206		0.44	1.81	**2.25**
G	1.54	1.96	0.00174		0.47	1.53	**2.00**
*H	1.58	1.90	0.00127		0.54	1.12	**1.66**
*H_1	1.60	1.87	0.00123		0.60	1.08	**1.68**
J	1.62	1.88	0.00105	0.0	0.70	0.93	**1.63**
*K	1.61	1.90	0.00122		0.54	1.07	**1.61**
*K_1	1.62	1.82	0.00129	0.4	0.55	1.13	**1.68**
†L	1.61	1.88	0.00118		0.535	1.035	**1.57**
†L_1	1.60	1.87	0.00129		0.515	1.135	**1.65**
B_1	1.61	1.81	0.00110	0.0	0.61	0.96	**1.57**
M	1.55	1.95	0.00115		0.55	1.01	**1.56**
N	1.62	1.90	0.00099		0.63	0.87	**1.50**
N_1	1.63	1.81	0.00107		0.64	0.94	**1.58**
P	1.64	1.88	0.00103	1.3	0.34	0.91	**1.25**
P_1	1.66	1.92	0.00094	0.7	0.43	0.82	**1.25**
Silicon steels							
†Q	1.63		0.00094	3.1	0.14	0.825	**0.965**
†Q_1	1.58		0.00102		0.16	0.90	**1.06**
R	1.64		0.00089	3.4	0.15	0.78	**0.93**
S	1.63		0.00086	3.5	0.12	0.755	**0.875**
T	1.68		0.00077	2.8	0.18	0.68	**0.86**
U	1.66		0.00084		0.12	0.735	**0.855**
U_1	1.68		0.00086	3.9	0.145	0.755	**0.90**
*V	1.68		0.00078		0.17	0.685	**0.855**
*V_1	1.67		0.00080	3.8	0.18	0.70	**0.88**
*W	1.67		0.00061	3.4	0.16	0.535	**0.695**
*W_1	1.64		0.00061		0.16	0.535	**0.695**
X	1.65		0.00062	3.2	0.12	0.545	**0.665**

altered. In the present cases, measurements were also made at 5,000 gausses and at 30 cycles. Separation of the losses after aging indicates which component is active. It is found that the hysteresis is nearly always responsible for the increase, although the eddy-current loss may be either increased or diminished.

The decrease in eddy-current loss may sometimes mask the increase in hysteresis. Thus specimen Q_1 immediately exhibited a decrease of 14 per cent in eddy-current loss, amounting to 2 per cent of the total loss. After 250 hours the hysteresis increased one per cent at 10,000 gausses, and 2 per cent at 5,000 gausses, and yet the total loss still showed a decrease. None of the other silicon steels showed any change in eddy currents, the slight changes in total loss being entirely due to increased hysteresis.

TABLE XII

PER CENT INCREASE IN TOTAL LOSS AT 60 CYCLES AND 10000 GAUSSES FOR DIFFERENT PERIODS OF AGING

Specimen	Time in oven					
	100 hr.	250 hr.	500 hr.	750 hr.	1000 hr.	2000 hr.
G	25	58	67	67	68	67
J	1	5	10	12	15	17
K_1		2	6	9	11	
L_1	-2	-1				
P_1		2	3	5		
Q_1	-2	-1				
R	0	0	0			
T		1	2	4		
U_1		0	0	0		
V_1		-1	0	0	1	
W		-2	-1	0	0	
X		0	0	3		

In the specimens G and J the eddy currents at first increased, but in the second thousand hours showed a marked decrease, which was sufficient to balance the steady increase in hysteresis. The result is a nearly stationary total loss. Specimen L_1 showed a slight initial decrease in hysteresis, and a later increase which was masked by decreasing eddy loss.

Specimen P_1 is a good example of the fact that the loss at different flux densities may be differently affected. The hysteresis throughout rose more rapidly at 5,000 than at 10,000 gausses, the increases amounting after 750 hours to 22 and 16 per cent respectively. This means that the law of variation of hysteresis with flux density has been changed. The exponent of B to which hysteresis is proportional has been diminished from $x = 1.66$ to $x = 1.60$. In the meantime the eddy currents have decreased, so that the increase in total loss at 10,000 gausses appears as only 5 per cent. Meanwhile, the total loss at 30 cycles and 5,000 gausses has increased 12.5 per cent. It is thus evident that an aging test should be conducted with measurements at the same flux density as that at which the material is to be used; otherwise the results may not apply to working conditions.

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CENTRALIZATION OF POWER SUPPLY

PRESIDENT'S ADDRESS

BY LOUIS A. FERGUSON

The most prominent characteristic of present-day industrial development is the tendency to consolidate. It is so apparent on every hand that this may well be called the Age of Centralization. The economies that may be effected by large production and centralized direction are being appreciated more and more, and extremely large industries have been, and are being, built up by combining many individual plants. In the main, such combinations have resulted in material benefits to the country and its people.

The lessened cost of wholesale manufacture permits a lower selling price, thus placing the commodity within easier reach of a larger number. The greater economy of production resulting from manufacture in large quantities and with improved methods is and will continue increasingly to be a material factor in that very important problem of the conservation of resources, which is so prominently before this and other countries at the present time.

In the industry of electric power production the advantages of centralization seem thus far to have failed somewhat of full appreciation, but the awakening is apparently at hand. In a few noteworthy instances centralization was planned and put into effect some years ago, and the work already done will blaze the way for others. When the economies of concentrated management and large production are more generally understood the growth of centralization will be rapid.

From whatever standpoint we view the problem the advantages stand out boldly. The investor will be more favorably impressed with large issues of securities which require no detailed information. These securities will be easily marketed and on much more favorable terms than is possible with the smaller issues of individual companies. Large as this saving is, by far the most important one results from the economies effected by combined investment and output. The load-factor of our central stations; that is, the ratio of the average load to the maximum load, absolutely controls the earning capacity of the investment. The cost of generating and distributing electricity consists primarily of fixed charges on the investment and of operating costs. The fixed charges are independent of the hours use of the equipment; therefore, if the load continues heavy for long hours daily the fixed charges are distributed over a larger output and the cost per unit of output is thereby lessened. In other words, with long hours use a greater output follows, and greater earnings are produced without any increase in the investment. Obviously, therefore, the greater the proportion the fixed charges bear to the total cost the greater will be the effect of the load-factor. In modern large power systems, as in water-power plants, the operating costs are now so low that they represent a comparatively small part of the total costs, the fixed charges constituting by far the larger part. The importance of a good load-factor is thus apparent and everything that will improve this factor should be sought.

The yearly load-factor for any one class of service is determined largely by the seasons, the habits of the people, and similar conditions which ordinarily do not change. Improvement in load-factor must therefore be obtained largely by combining different classes of service, the maximum demands of which occur at different times of the day or of the year. Also, the larger the number of customers in any class the better will be the load-factor.

The ratio between the sum of the maximum demands of various classes of service to the actual simultaneous maximum demand is termed the diversity factor, and the more non-coincident peak service that is combined in one system the greater will be this factor. It is here that centralization presents its most marked effect in increasing the load-factor and thereby the economy of production. The addition to a central station system of business having a high load-factor, such as power business for all-the-year-round service, amusement parks, auto charging and refrigeration for the summer, utilizing the otherwise idle investment, is desirable not only in itself but also because it reduces the cost of the entire output.

The whole community through this reduction in cost is thus benefited by centralization, since the central station company is enabled to sell its product at a lower price to the small consumer because of the improved condition of manufacture effected through the supply of its product to the large consumer.

In the power station the larger output of combined loads will permit the use of large generating units which have a high performance efficiency, and which require a comparatively small operating force. This results in further reduction of costs. The investment per kilowatt, not only for the apparatus but for the land and building as well, is also less for large units, and the total reserve required by the centralized system will be but a small fraction of the combined reserve required where the load is furnished from individual systems. The saving in investment in this single item of reserve alone is an important factor in the problem. One of the leading causes for the success which has attended the development of the electrical industry in this country has been the standardization of equipment, and the American Institute of Electrical Engineers has been the active leader in this important work. It is still a far cry to the ideal but all steps taken should be in the forward direction. Centralization leads toward standardization. In the present state of the art, generation will be by three-phase alternating current and the predominating demand will determine the frequency, be it 25 or 60 cycles or some other frequency. If, however, the demand in any community for an auxilliary standard frequency becomes sufficiently large even though it remain a small part of the total output, then generation at this auxiliary frequency is justified; but connecting links of ample capacity should be provided between the sets of generators of different frequency so that the advantages of the diversity factor and of common reserve may still obtain. The voltage should also be so chosen that the transmission cable may be interchangeable between the two systems.

An incidental advantage of centralization, which, however, is of great sociologic importance in a community, is the resultant cleanliness due to the absence of countless smoking chimneys. This fact is being actively recognized by civic improvement bodies and such recognition is a valuable asset to a central station company in the prosecution of its industrial power campaign.

One of the early and prominent examples of centralization is found in England where the Newcastle-upon-Tyne Electric

Supply Company furnishes energy to one of the most important manufacturing areas in the United Kingdom. A special effort has here been made to develop particularly the industrial power business and the general adoption of electricity has had a marked effect on the industrial conditions in that district. The tramways are operated from this system as well as electrified steam roads. In many of the smelting mills the waste gases are used to produce steam in boilers and the energy thus derived is used in turbine stations and is fed into the general system, the same smelting mills being in turn customers of the supply company. The total load is not so very large compared with that in some of our American cities, but this system is mentioned in such detail because it typifies what can be done in the way of centralization. There is still a good deal of independently produced power in the district, but it will undoubtedly eventually be won over by the supply company. Even though the difference in efficiency between the smaller turbine units and the larger units is decreasing, the diversity factor will in most cases enable the supply company to underbid independent producers.

The diversity factor is the very foundation rock of centralized energy supply. It is the birthright of the central station, the fundamental reason for its existence and its resultant value belongs to the central station company.

In some American cities, as already stated, the total load is considerably greater than in the example just cited, but the centralization possibilities are only just beginning to be developed.

The system of the Pacific Gas & Electric Company with its hundreds of miles of transmission lines, its many customers among the mines dotting the hills, and the many cities receiving electrical power from the company, is perhaps the nearest approach to the Newcastle system. At Niagara the transmission lines are reaching out in all directions and we may hope to see one of the great industrial centers of the future in that locality. At the present time there are many independent companies, and the full benefits of centralization will not be realized until the stations are loaded up to the point where they will be compelled to arrange for interchange of energy.

Chicago, because of its strategical location regarding transportation, is certain to remain one of the world's greatest markets and industrial centers. If the imagination were allowed full play the possibilities in power requirements of the future in the Chicago districts would appear almost boundless. A vigorous start toward centralization of power production has already been made. Street-railway power houses have been shut down and the energy for the operation of the street railways is purchased in whole or in part from the central station company.

The supply of power for electrified steam railways is one of the possibilities of the near future and engineering plans and expenditures of past years have been made with a view of taking care of wholesale industrial business on a comprehensive scale.

In a large number of cities two prominent public services—street railways and electric lighting—were originally inaugurated by one company, and with the natural growth and development of the two systems the electrical generation has in many cases been unified so that one set of generators furnishes energy for both railway and lighting. However, in most of these cities the industrial power business has not been vigorously developed either because of lack of appreciation of its value or timidity on the part of the supply company in making sufficiently low prices to obtain the business.

There are also very few, if any, communities or territories in which the centralization of power supply for all purposes has been effected and in which electric power is utilized in such manner that the best economic results are realized. By combining all systems of neighboring cities within a radius of 30 or 40 miles into a single centralized system a great saving in production would result and in most cases an improvement in service as well. The utilization of water powers will help in this direction.

The monopolistic character of the electric power industry is now being recognized by the intelligent public and monopoly privileges with proper regulation are being granted as the best safeguard for the interests of the people. The legal way is thus being paved for the beginning of centralization. Such centralization will naturally include the power for electrified steam railways, the universal coming of which is but a matter of time. In most instances the total amount of power required by a railroad for its terminal and suburban service, even where counted in the tens of thousands of kilowatts, is but a small part of the total power required for all purposes within the same area.

If this railway power is generated in a separate plant the load-factor would be far below that of the central station and the necessary reserve capacity would require a high fixed charge to be carried by the plant. With less reserve the reliability of the service might suffer disastrously. No railroad could thus generate its own power as cheaply or as securely as it may be purchased from a properly directed central station company. This applies also and to an even greater extent to power production for industrial uses or to individual generation for any purpose.

In cities where the power production is not centralized, a multiplicity of systems of voltages and often of frequencies is usually found, and the duplication which spells waste is abundant.

Without the economies resulting from centralization the price of the output will necessarily remain higher than otherwise and the community must pay the cost. With the lower efficiency of generation the fuel resources are wasted and the entire country will ultimately suffer as a result.

It has seemed to me that a condition of such transcendent importance to the electrical profession should receive liberal attention and consideration from our Institute. We, as an organization, have a large part to play in the development of the art of electrical application as well as in electrical science.

There is scarcely any branch of the electrical industry which does not ultimately affect or which is not in a measure affected by this development.

The progressive work of the electrical engineer will determine with what success we can reach out into these larger fields. The mechanical engineer has given us a steam turbine of greatly improved economy; it is for us to improve still more the method of transmission and conversion and the application of electricity in the arts. High-voltage transmission made possible our entry into this field, but, while very great advances have been made, there are still some unsolved problems in this field and particularly with regard to underground transmission. There are also many problems and countless opportunities in connection with the utilization of electrical energy. The successful solution of these problems is of the utmost importance.

It is for the commercial electrical engineer (which really includes nearly all of us) to educate the layman and particularly the power user to an appreciation of the superiority and desirability of electric service and to emphasize the material and ethical advantages to a community of centralized power production.

It is for the technical electrical engineer to furnish him with the sinews of war, with the ammunition to conquer in the fields where waste, where useless dissipation of energy prevails. We should bend every effort to advance the cause of centralization with its resultant economic gains. Those connected with the manufacturing interests especially should not tolerate for an instant a selfish backward step within their fold.

As we meet here in convention to gain a broader knowledge and to discuss important problems let us think of these opportunities which our profession affords in this grand movement for world betterment, this guiding of the forces so that Nature's bounty to man will bring to him the highest and greatest good. The thought carries with it inspiration and enthusiasm and a determination to do our part, individually and collectively, in the successful upbuilding of an industry which means so much to the economic development of the country's resources.

Some day, in the centuries yet unborn, the broadening perspective of time will show more clearly the full significance of these days' accomplishments. Surely, gentlemen, nothing could be more inspiring to greater effort than the knowledge that we have in our hands the means for this achievement.

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POLE-FACE LOSSES

BY COMFORT A. ADAMS, A. C. LANIER, C. C. POPE, AND C. O. SCHOOLEY

INTRODUCTION

The object of the experiments recounted below was to establish a reliable and if possible a *rational* quantitative relation between the pole-face losses and the principal variables involved therein. The work was originally undertaken as a supposedly small part of a larger investigation without any realizing sense of the amount of work involved or of the difficulty of obtaining reliable results. Another time the method employed would be modified in the light of this experience, but although the results are not altogether satisfactory from the standpoint of the investigator, they are sufficiently accurate for most practical purposes, and it is believed more reliable than those heretofore published.

The experimental work was so recently completed that it will be impossible at this time to give the results, or their analysis, in a thoroughly digested form.

THEORY

In any dynamo-electric machine with a toothed armature the magnetic flux density at the pole-face opposite a tooth is greater than that opposite a slot, and as the armature rotates, the teeth carry waves of flux across the pole faces; that is, each point on the pole face is subjected to a pulsating flux density which gives rise to eddy currents in the mass of the pole face. Some energy is also dissipated by magnetic hysteresis, but at the ordinarily high tooth-frequencies the eddy-current loss predominates; with solid pole faces the hysteresis loss is negligible. In any case these phenomena are so complex from the standpoint of quantitative analysis that it is practically impossible to separate the two losses.

Were it not for the magnetomotive force of the eddy currents themselves the flux would distribute itself, both outside and inside of the pole shoe, in such a way as to correspond to the minimum total reluctance; that is, the flux pulsations would gradually die out and the flux tend toward uniform density in proceeding from the pole face back into the mass of the pole shoe. But the eddy currents materially hasten this equalization in their effort to damp out the flux pulsations of which they are the result. This effort to equalize the flux density is maximum at the surface of the pole shoe where the maximum pulsation takes place, and it undoubtedly alters to some extent the flux distribution over this surface.

Within the pole shoe the disturbance is propagated in the familiar manner of electromagnetic waves, the attenuation constant being very large, owing to the high permeability and conductivity of the medium and the relatively high frequency of the pulsation, the penetration wave-length being very short for the same reason.

With solid pole shoes and average constants the wave is practically damped out at a distance back from the pole face equal to about one millimeter, the pulsation being thus confined to a very thin surface layer.

With laminated pole shoes the conditions are quite different. This difference can easily be understood by reference to Figs. 1 and 2. Fig. 1*a* is a plan view and Fig. 1*b* an elevation of a solid pole shoe, together with the teeth. Fig. 1*c* shows an assumed sinusoidal flux variation at the pole face. In Fig. 1*a* approximate eddy-current paths are shown in light lines; the directions as indicated by the arrows correspond to a right-to-left movement of the teeth across the pole face. The transverse portions of the currents are the ones which produce the damping of the flux pulsations and are predominant in the case of solid shoes; they will be referred to as the *damping currents*.

With ordinary proportions of teeth and pole face, those parts of the eddy currents in the circumferential direction are relatively small; their tendency is to screen the center of the pole from the flux pulsations and to drive the latter to the two circumferential edges; these circumferential portions of the eddy currents will therefore be called the *screening currents*. With solid pole shoes the screening currents may safely be neglected.

Fig. 2*a* is a plan view of a portion of a *laminated* pole shoe showing the approximate eddy-current paths at the pole face, and Fig. 2*b* is an elevation of the pole shoe. Except for the laminations, Figures 1 and 2 are intended to represent the same conditions.

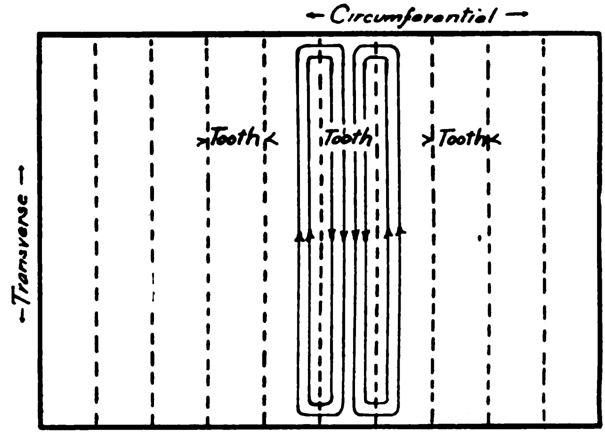

Fig. 1a

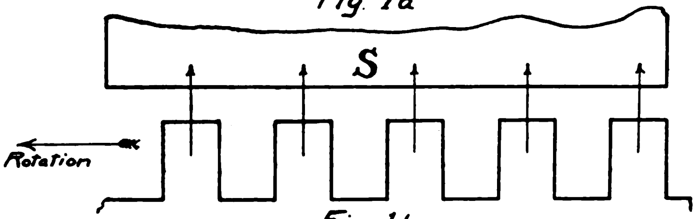

Fig. 1b

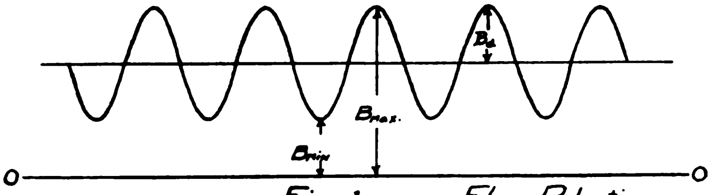

Fig 1c Flux Pulsation at Pole Face

In the case of laminated pole shoes represented in Figs. 2a and 2b the circumferential or screening currents predominate, and the transverse or damping currents are not only greatly reduced in magnitude but also in effectiveness; that is, the pulsations will penetrate much deeper into the pole shoe and the advantage of the laminations will be considerably neutralized.

Both the damping and the screening currents have the same origin and nature. The damping currents try to check the penetration of the flux pulsations into the pole shoe perpendicular to the face, and the screening currents tend to check the penetration of the flux pulsations into the laminæ from the side surfaces towards the center. The chief difference is that

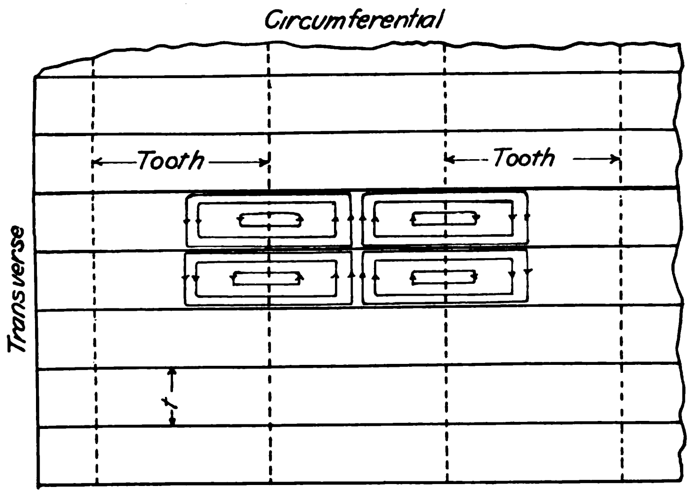

FIG 2a

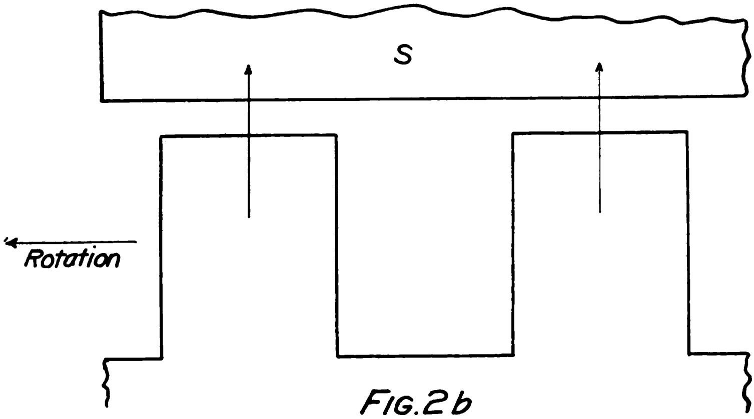

FIG.2b

whereas the damping currents tend to force a more uniform circumferential flux distribution the screening currents tend to disturb an otherwise uniform transverse flux distribution across the section of the laminæ. Both tend to increase the reluctance of the magnetic circuit and to decrease the eddy-current loss. The screening currents, however, tend to increase the hysteresis loss, other things being equal.

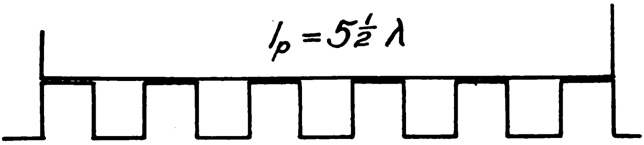

FIG. 3.

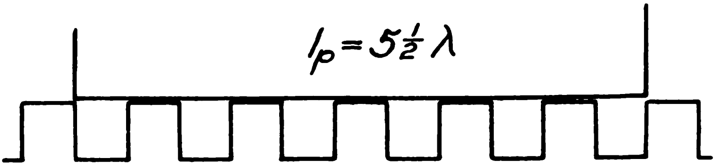

FIG. 4.

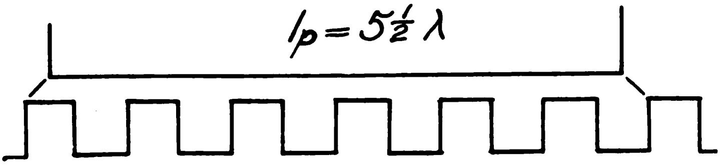

FIG. 5.

There is another source of energy loss in the pole face which is in some cases of considerable magnitude. It is that due to the *pulsation of reluctance of the main magnetic circuit* caused by a variation in the number of teeth under a pole. For example, if the pole arc (l_p) is just five and a half times the tooth pitch (λ), and if the air gap be very short, there will be positions of the armature where there are six teeth under a pole face and other positions where there are only five, there being a variation of reluctance of about 15 per cent between these two positions (see Figs. 3 and 4). Such a variation would cause a pulsation of flux through the whole magnetic circuit and a consequent loss of energy. Of course this variation could be largely eliminated by chamfering the corners of the pole shoes.

On the other hand if the air gap be larger, say about equal to one-quarter of the tooth pitch, the fringing from the pole corners would add about a half tooth pitch to the equivalent pole arc, making it just about six times the tooth pitch. In this case there would be practically no reluctance variations, since the number of teeth under the equivalent pole arc is constant (see Fig. 5).

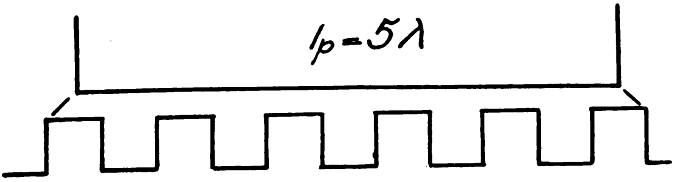

FIG. 6.

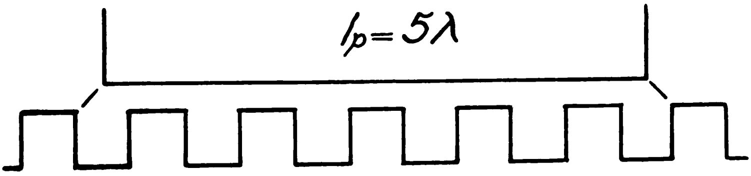

FIG. 7.

If the actual pole arc is just six times the tooth pitch, the minimum reluctance pulsations occur with a short gap and the maximum with a fairly long gap (see Figs. 6 and 7).

As an example, consider the apparatus used by Wall and Smith[1] for the investigation of pole-face losses. The pole face was solid with square corners, and the actual pole arc was just three and a half times the tooth pitch. Thus with fairly long gaps the reluctance pulsation loss was a minimum, and with very short gaps a maximum. The pulsation was very large at short gaps owing to the large percentage of reluctance variation, probably about 25 per cent. As this part of the loss was not recognized at the time, it made the pole-face loss appear to increase with decreasing air gap at least twice as rapidly as it should have done. This entirely masked the phenomena under consideration.

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[1] Institution of Electrical Engineers, London, June, 1908, Vol. 40, p. 577.

This loss was also overlooked in the results of Dexheimer's experiments,[2] where considerable discrepancies can thus be accounted for.

Returning now to the damping currents and screening currents, these have both been analysed theoretically, but each independently of the other, the former for the case of solid pole shoes by Potier[3] and Rüdenberg,[4] and the latter for laminated cores by Steinmetz.[5]

Solid pole shoes. Consider a solid pole shoe subjected to tooth flux waves, and neglect the circumferential or screening currents.

Let λ = the tooth pitch in cm., and
v = the velocity of the armature periphery in cm. per second.

Analyze the circumferential flux distribution curve at the surface of the pole face into its fundamental and harmonics, (the wave length of the fundamental being λ), and consider separately the loss due to each.

Let B_1 = the amplitude of the fundamental pulsation, and
B_n = the amplitude of the nth harmonic.

Let μ = the permeability of the pole face and
ρ = its electrical resistivity in absolute electromagnetic units.

Then it can be shown[3 & 4] that the pole-face loss in watts per sq. cm., due to the fundamental pulsation wave, is approximately

$$P_1 = \frac{B_1^2}{8\pi} \sqrt{\frac{v^3 \lambda}{\mu \rho}} \, 10^{-7} \qquad (1)$$

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[2] "Die Gleichstronmaschine," E. Arnold, Vol. I, second edition, page 649.

[3] L'Industrie Electrique, 1905, p. 35.

[4] Elektrotechnische Zeitschrift, Vol. 26, 1905, p 181.

[5] "Transient Phenomena", p. 355.

and that the corresponding attenuation constant is approximately:

$$\beta_1 = 2\pi \sqrt{\frac{\mu v}{\rho \lambda}} \tag{2}$$

It is somewhat surprising that in equation 1 the pole face loss is proportional to the 3/2 power of the velocity (and therefore of the tooth frequency) rather than to the second power. But this is after all only reasonable, since the greater damping action at the higher frequencies reduces the equivalent depth of the active layer; that is, the attenuation constant is larger and the flux wave does not penetrate as deeply into the pole shoe.

In applying equations 1 and 2 to the harmonics of the flux pulsation, it should be remembered that whereas λ, the tooth pitch, is also the circumferential wave length for the fundamental, the circumferential wave length for the nth harmonic is, $\lambda \div n$.

Neglecting the influence of the damping currents and of saturation upon the flux distribution at the pole face, B_1, B_2, B_3, etc., are proportional to the average pole face density B and may be written,

$$B_1 = k_1 B, \qquad B_2 = k_2 B, \qquad B_3 = k_3 B, \text{ etc.}$$

Then from equation (1),

$$P_1 = \frac{10^{-7}}{8\pi} k_1^2 B^2 \sqrt{\frac{v^3 \lambda}{\mu \rho}} \text{ and } P_n = \frac{10^{-7}}{8\pi} k_n^2 B^2 \sqrt{\frac{v^3}{\mu \rho} \frac{\lambda}{n}} \tag{3}$$

The ratio of the amplitude of the nth harmonic to that of the fundamental or the per cent of nth harmonic is, $k_n \div k_1 = a_n$.

Then:

$$P_n = P_1 \frac{a_n^2}{\sqrt{n}} \tag{4}$$

and the total pole-face loss in watts per square centimeter, is:

$$P = \frac{10^{-7}}{8\pi} k_1^2 B^2 \sqrt{\frac{v^3 \lambda}{\mu \rho}} \left(1 + \frac{a_2^2}{\sqrt{2}} + \frac{a_3^2}{\sqrt{3}} + \text{etc.}\right) \tag{5}$$

or

$$P = \frac{10^{-7}}{8\pi} k^2 B^2 \sqrt{\frac{v^3 \lambda}{\mu \rho}} \tag{6}$$

where $$k^2 = k_1^2 \left(1 + \frac{a_2^2}{\sqrt{2}} + \frac{a_3^2}{\sqrt{3}} + \text{etc.} \right) \tag{7}$$

The watts per square inch of pole face is given by equation (6*a*) where B = average pole face density in maxwells per square inch, v = peripheral velocity of the armature in feet per second, λ = tooth pitch in inches, and ρ and μ are the same as before.

$$P'' = 1.65 \times 10^{-7}\, k^2 B^2 \sqrt{\frac{v^3 \lambda}{\mu \rho}} \tag{6a}$$

Thus $k\,B$ is the amplitude of the *equivalent* sinusoidal pulsation, and the problem resolves itself into the determination of k. The k's and the a's are obviously wholly dependent upon the shape of the flux distribution curve, which in turn is wholly dependent upon b, the ratio of slot opening (w_s) to the tooth pitch (λ), and q, the ratio of slot opening to air gap (δ). Unfortunately the k's and the a's are exceedingly complex functions of these two variables, even under the assumption made above as to neglecting the effect of damping currents and saturation upon the pole-face flux distribution.

Of the two variables involved in k, b ($= w_s \div \lambda$) has for open slot machines a fairly narrow range of variation, being rarely found outside of the range from 0.4 to 0.6 with an average of 0.5.

Then if b is fairly constant, k is largely dependent upon the ratio

$$q = w_s \div \delta$$

that is, with a given value of b, k will be a function of q. As a general determination of k appears to be practically impossible, it will be necessary to consider a few special cases in order to get an idea of the nature of its variation.

For very large gaps, q is small and k obviously approaches zero.

For four other points (q = 2, 6, 12 and 24, and $b = 0.5$), flux distribution curves were carefully worked out with the aid of the experimental results of Wall.[7] These curves were then analyzed and k^2 computed according to equation 7. The resulting values of k^2 are plotted in Fig. 8.

For larger values of b, k would be somewhat larger, and smaller for smaller values of b. But within the ordinary range these differences are small.

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[7] T. F. Wall. Journal of the Institution of Electrical Engineers, June 1908. Vol. 40, p. 550.

In using Fig. 8 it should be remembered that even if the flux distributions had been determined accurately from the static standpoint, the eddy currents in the pole shoes tend to alter the static distributions at the surface in the direction of decreasing their variation. The reluctance of saturated teeth also tends in the same direction. Neither of these sources should under ordinary conditions give rise to considerable variations from the results shown in Fig. 8.

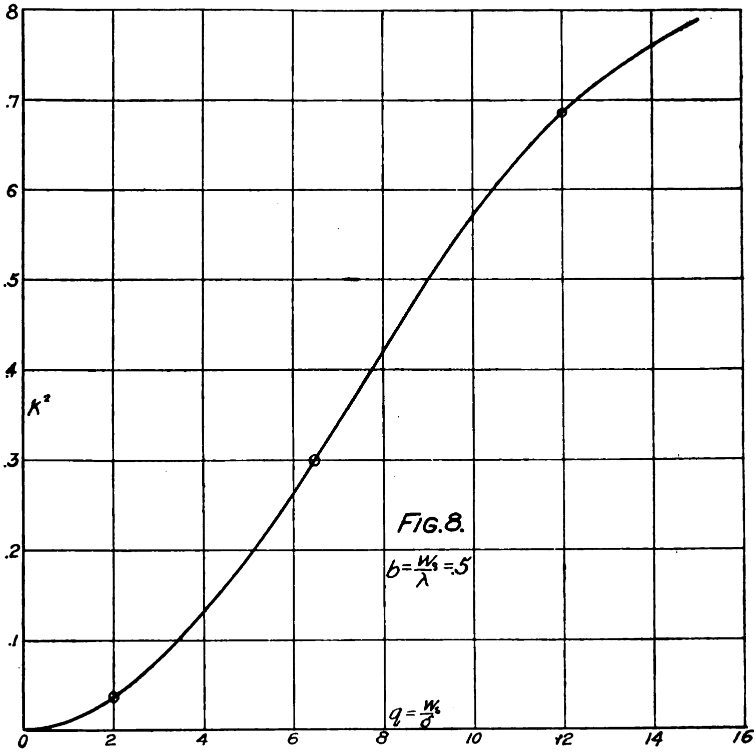

FIG. 8.

Equation (6), together with Fig. 8, thus gives a fair idea of the factors which determine the pole-face losses in the case of solid shoes.

Laminated pole shoes. Although any reasonably complete analytical treatment of this case would be extremely complex and tedious, if not impossible, it is possible with the aid of equation 6 (for solid poles) to make some roughly quantitative deductions as to the effect of laminations.

Referring to Fig. 9, assume the eddy currents to flow in symmetrical paths as shown, and consider the element *a b* of the damping current. This element experiences exactly the same electromotive force as in the case of the solid pole shoe, but the resistance of its path is $\left[1+\left(\frac{\lambda}{2t}\right)^2\right]$ times as great as for the solid shoe, where t is the thickness of the laminations and λ the tooth pitch. These damping currents will thus have the same effect with respect to those of the solid shoe as if the specific resistance were increased in the ratio $1+\left(\frac{\lambda}{2t}\right)^2$, or approximately $\left(\frac{\lambda}{2t}\right)^2$. This assumes the same quality of iron in the two cases. It will also be observed that the system of damping currents thus established does not cross the full thickness of the laminæ although the more important longer currents which flow in the longer paths do flow nearly across. The effect of this restriction in length of the damping currents is obviously to

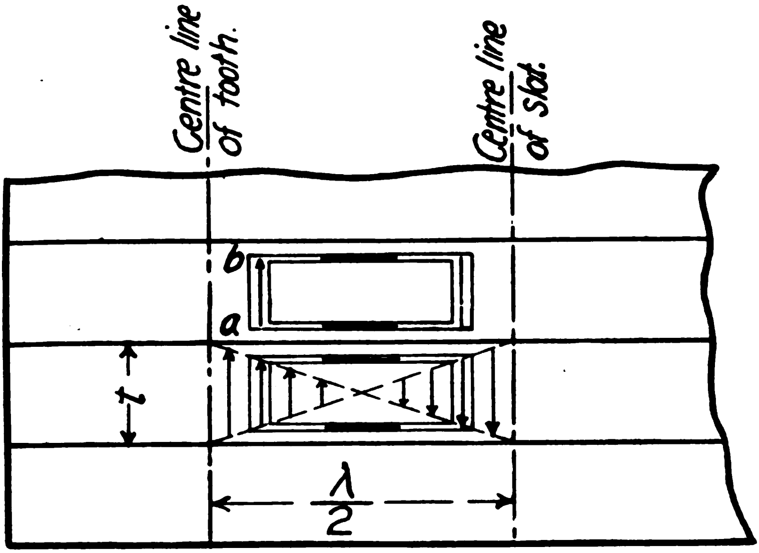

FIG. 9.

reduce the damping effect, to allow the flux to penetrate deeper near the lateral surfaces of the laminæ, and thus to increase the loss slightly.

Thus with the same quality of iron as in the solid shoes the principal effect of laminating may be represented by an increase of specific resistance in the ratio $\left(\frac{\lambda}{2t}\right)^2$. By introducing this ratio into equation 6 together with a constant *a* to take account of the shortened damping-current paths, we obtain for the watts per square centimeter of pole face for laminated pole shoes:

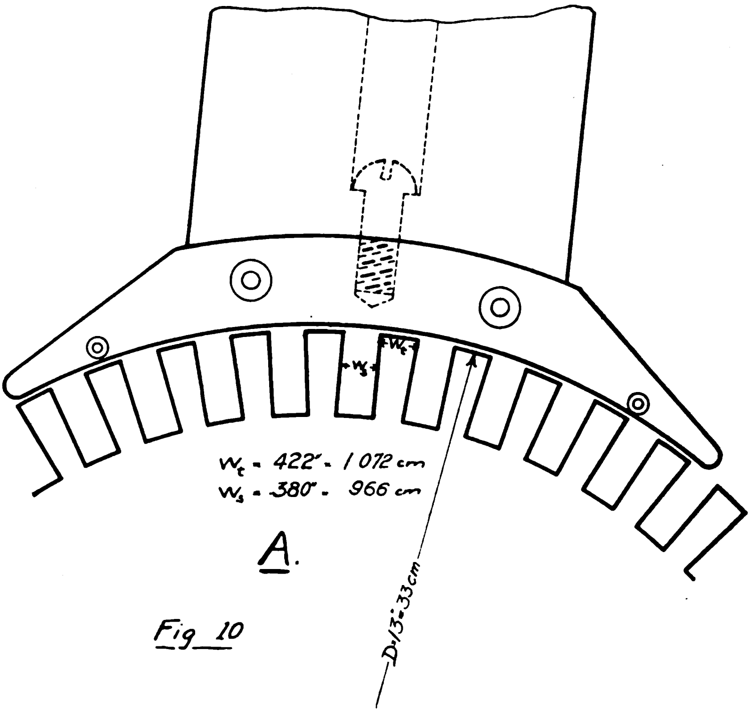

Fig 10

$$P_l = P\,a\,\frac{2t}{\lambda} \tag{9}$$

or

$$P_l = \frac{10^{-7}}{8\pi}\,k^2\,B^2\,a\,\frac{2t}{\lambda}\sqrt{\frac{v^3\lambda}{\mu\rho}} \tag{10}$$

or

$$P_l = 7.96\times10^{-9}\,a\,t\,k^2\,B^2\sqrt{\frac{v^3}{\mu\rho\lambda}} \tag{11}$$

It is interesting to note that whereas the solid pole-shoe loss is proportional to $\sqrt{\lambda}$, that for the laminated shoes is inversely proportional to $\sqrt{\lambda}$.

Reduced to the same units as for equation 6*a*, the watts per square inch are:

$$P_l'' = 3.3 \times 10^{-7}\, a\, t\, k^2 B^2 \sqrt{\frac{v^3}{\mu \rho \lambda}} \qquad (11a)$$

It should be noted that perfect insulation of the laminæ is assumed, otherwise P_l will be larger.

These theoretical equations are crude, not only because of the assumptions and approximations involved in their development but also because no account whatever is included of numerous minor sources of loss, some of which become prominent in certain limiting cases; but they serve very well as a basis for the interpretation of the experimental results. Experimental results without some such interpretation are apt to have a very limited range of usefulness, or in some cases to be worse than useless.

EXPERIMENTAL RESULTS

Apparatus. The machine employed was provided with detachable poles and pole shoes, and with three armatures, each with a different number of teeth. Three sets of pole shoes were used, one set of solid annealed steel castings, one set of 0.014 in. laminations, and the third set of 0.06 in. laminations.

The laminated pole shoes were held together by insulated bolts and were held on the poles by screws tapped in from behind so as to leave the pole face unbroken. The pole shoes were bored concentric in place; they were then taken down, the tool burrs were removed, and the poles carefully replaced.

The air gap was varied by means of shims placed behind the pole pieces. As the pole face could not be concentric with the armature at all gaps without reboring for each gap, an equivalent corrected gap was computed when necessary.

The dimensions of the pole shoes and armature teeth are given in Figs. 10, 11, and 12.

The losses were measured by running the machine light as a motor, measuring the input and subtracting the other losses as below.

Constant-speed tests. The field current and armature voltage were varied over a wide range in such a way as to maintain a constant speed of 1246 rev. per min. By plotting a curve of watts lost *versus* volts, the friction loss was determined. This together with the armature copper and brush losses were then subtracted from the total to get core loss plus pole-face loss. By plotting core loss plus pole-face loss versus air gap and extending the curve slightly the core loss was determined. This was then subtracted to get the net pole-face loss.

Constant flux tests. The exciting current was maintained constant and the speed varied over a wide range by varying the armature voltage. The object of these tests was to check the exponent of v in equations 6 and 11.

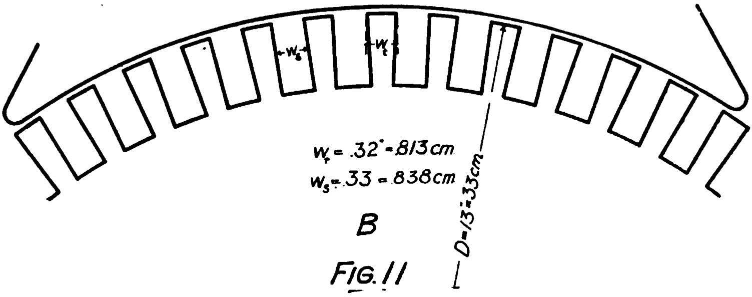

FIG. 11

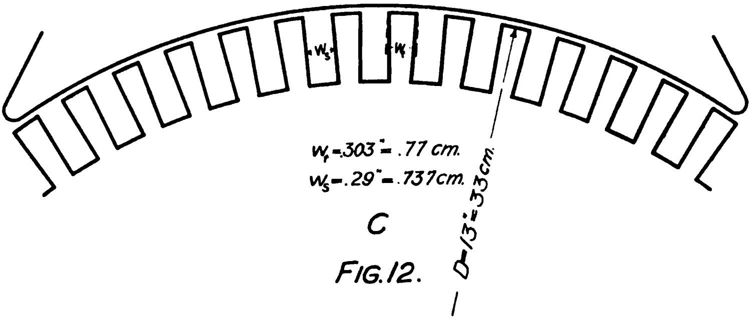

FIG. 12.

These two tests were made with numerous combinations of three armatures, three sets of pole shoes and five air gaps.

Errors. The greatest care was observed in the conduct of the experiments, the measurement of the air gaps and in working up the results; but errors undoubtedly crept in, in addition to those inherent in the method. Of the latter the following are the most obvious; (*a*) errors due to heating of pole shoes and consequent change of specific resistance; (*b*) errors due to distortion of flux under pole face by armature current; (*c*) variation of the friction loss during the test; (*d*) variation of core loss with air gap.

a. The heating element was largely eliminated by starting the tests cold and not carrying them far enough to cause a troublesome rise of temperature. Within the range of the results given below the maximum temperature variation was less than 20 degrees cent. which means about 3 per cent variation in the pole-face loss, since the specific resistance enters equation 6 as the square root.

b. The distortional effect is negligible except for short gaps, being much larger of course for the solid poles and least for the 0.014 in. laminations. But this error becomes rapidly a serious one when it once begins to count, since it means an increase in armature core loss, which increase—by the method of elimination already outlined—appears in the pole-face loss; thus the apparent pole-face loss is doubly increased. This effect results in raising the apparent exponent of v and of q in the loss equation.

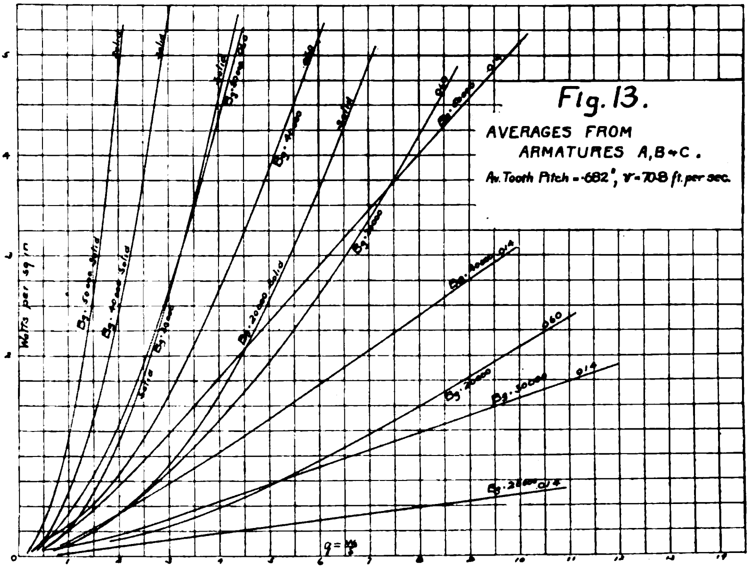
Fig. 13.

AVERAGES FROM ARMATURES A, B + C.

Av. Tooth Pitch = .682", v = 70.8 ft. per sec.

c. A large part of the friction being brush friction, this item was subject to an appreciable variation although the greatest care was employed to keep the commutator clean and of uniform polish. All brushes except two, one positive and one negative, were removed from the holders during the tests.

d. The longest gap obtainable was not long enough to eliminate the pole-face loss entirely, hence it was necessary to prolong the curves, (*pole-face loss* + *core loss* versus *gap*) in order to separate the core loss from the total; but although this prolongation can be made and the core loss determined with a very fair degree of accuracy, the result is the long-gap core loss which is undoubtedly less than that with a very short gap. This error would tend to raise the apparent exponent of q.

The friction error is more or less erratic, but the other three increase with the pole-face loss, the heating error being subtractive and the other two additive. They thus neutralize each other in part, although the heating error is probably less than the other two.

Exponents. By plotting P versus B (for constant speed) on logarithm paper, the exponent of B was determined. By similarly plotting P versus v (for constant B) the exponent of v was determined.

The average exponent of B taken from some forty-five sets of observations is

2.5 for the solid pole shoes
2.4 for the 0.06 in. laminations, and
2.3 for the 0.014 in. laminations.

The fact that the exponent is larger than 2, is probably due, partly to the decrease of permeability at high densities and partly to eddy currents in slot conductors and other abnormal localities. These hardly seem sufficient however to produce as much increase in the exponent as that observed. In the experiments of Wall and Smith both distortional and core-loss errors were practically eliminated and they obtained an exponent for B of 2.1 for solid pole shoes. This should stand as fairly reliable were it not for the predominance of the reluctance pulsation loss in their experiments, and for the fact that only a single set of observations was made.

It is interesting to note that in these experiments the armature core loss itself increased about as the 2.1 power of the flux density; this is doubtless due to the distortional increase.

The average exponent of v was 1.55, a little larger than the theoretical value of equation 6. The apparent excess is probably due to distortional errors.

The variation in λ between the three armatures was not enough to check its exponent, but its effect is quite obvious in the curves of Fig. 14.

An inspection of the computed curve of k^2 in terms of q, (Fig. 8) and the curves of P versus q in Fig. 13, will show that while these curves are not all clearly exponential with respect to q, some of them are very close to that form throughout a considerable part of their length. If it were possible thus to express k^2 as a simple exponential function of q even over a moderate range of that variable, it would be possible to formulate the pole-face loss in a comparatively simple manner.

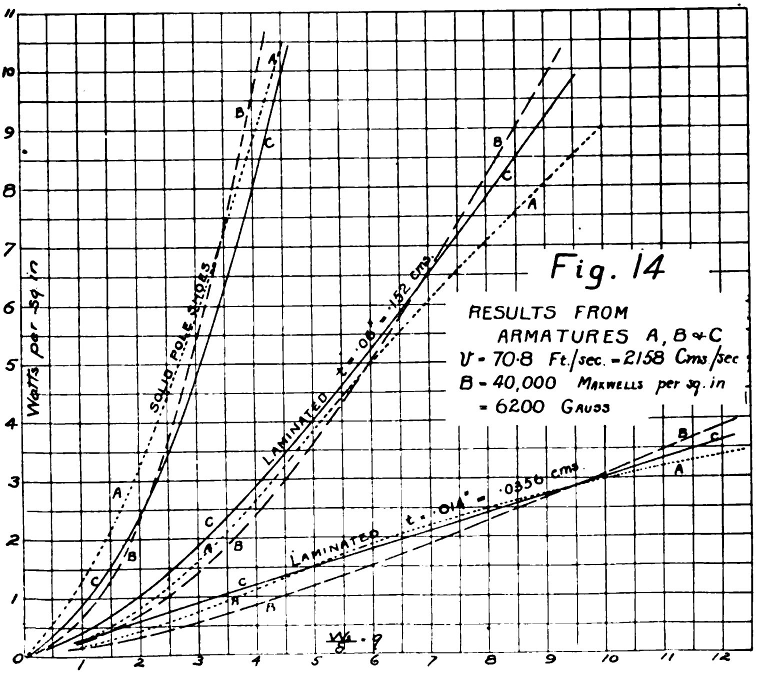
Fig. 14

To this end the theoretical and experimental results were plotted on logarithm paper and the exponents of q averaged.

The lower part of the curve of Fig. 8, covering the working range up to $q = 6$, gave an exponent of 1.8. With armatures B and C the reluctance pulsation loss, increasing with decreasing gap, increased the apparent exponent of q, but the reverse was true of armature A and the average of all three should be fairly reliable; it is, 1.88 for the solid pole shoes, 1.50 for the 0.06 in. laminations and 1.22 for the 0.014 in. laminations.

The reason for the lower exponents for the laminated shoes is at least partly due to the *screening* effect within the section of each lamina, tending to force the flux and the eddy currents to the lateral surfaces. This screening is not at all negligible at the high tooth-frequencies employed in the experiments here described, even with the 0.014 in. laminations. The effect of the screening is to decrease the eddy currents by contracting the eddy-current paths and to increase the hysteresis loss by confining the same amount of flux in a reduced cross-section. Both of these effects tend to reduce the exponents of q. Another factor which contributes to a greater extent to these low exponents, is the reluctance pulsation loss which, although small for the long gaps, is large when compared to the small pole-face losses, and thus lifts the lower parts of the P versus q curves by a considerable amount; but the experimental exponents are nevertheless fairly reliable for practical purposes, since they represent fairly average conditions and include the reluctance pulsation losses.

Comparing Fig. 8 with the experimental curves of Fig. 14 it will be observed that the curves for armatures B and C do not show the inflection of Fig. 8, but that the curves for armature A show even an earlier inflection. The reason for this is that the reluctance pulsation loss which in B and C increase with q, in A decreases with q, hiding the inflection in the first case and emphasizing it in the other. As between B and C the former has the larger reluctance-pulsation loss at very short gaps partly because of the larger tooth pitch and partly because of the better ratio between the pole arc and tooth pitch. Thus the B curve crosses the others in each case in the upper range of values.

Formulation of experimental results. Disregarding variations in μ and ρ, the results of the experiments described above may be roughly summed up in the following semi-empirical formulæ. In c.g.s. units, as for equations 1, 6 and 11, they are—

For solid pole shoes:

$$P_s = \frac{2.65}{10^4}\left(\frac{B}{10^3}\right)^{2.5}\left(\frac{v}{10^3}\right)^{1.55} q^{1.88}\sqrt{\lambda} \qquad (12)$$

For 0.06 in. laminations:

$$P_{.06} = \frac{0.985}{10^4}\left(\frac{B}{10^3}\right)^{2.4}\left(\frac{v}{10^3}\right)^{1.55} q^{1.5}\frac{1}{\sqrt{\lambda}} \qquad (13)$$

For 0.014 in. laminations:

$$P_{.014} = \frac{0.705}{10^4} \left(\frac{B}{10^3} \right)^{2.3} \left(\frac{v}{10^3} \right)^{1.55} q^{1.22} \frac{1}{\sqrt{\lambda}} \qquad (14)$$

In inch units, the same as for equation 6*a*, these equations become:

For solid pole shoes:

$$P_s'' = \frac{12.9}{10^4} \left(\frac{B}{10^4} \right)^{2.5} \left(\frac{v}{10} \right)^{1.55} q^{1.88} \sqrt{\lambda} \qquad (12a)$$

For 0.06 in. laminations:

$$P_{.06}'' = \frac{4.62}{10^4} \left(\frac{B}{10^4} \right)^{2.4} \left(\frac{v}{10} \right)^{1.55} q^{1.5} \frac{1}{\sqrt{\lambda}} \qquad (13a)$$

For 0.014 in. laminations:

$$P_{.014}'' = \frac{3.15}{10^4} \left(\frac{B}{10^4} \right)^{2.3} \left(\frac{v}{10} \right)^{1.55} q^{1.22} \frac{1}{\sqrt{\lambda}} \qquad (14a)$$

These apply only to the particular conditions of the test as to reluctance pulsation loss, insulation of laminations, μ, ρ, etc., and should be used accordingly. The reluctance pulsation loss was larger in these experiments than with the ordinary chamfered pole tips, but not large enough to give more than a reasonable margin in calculation.

Curves. The most important experimental data from the practical point of view are summarized in the curves of Fig. 13, which show the relation of P (the pole-face watts per square inch) to q (the ratio of slot opening to air gap).

Curves for several densities and for the three different sets of pole shoes are shown. Each curve represents an average for the three armatures and corresponds to a speed of 1246 rev. per min. or a peripheral velocity of 70.8 ft. per sec. = 2160 cm. per sec.

The only apparent reason why the results from the three armatures averaged above should differ, is that the tooth pitches are different; but since λ enters equation 6 as the square root, any moderate difference such as exists between these three armatures does not produce a considerable difference in the pole-face loss. In the present instance this difference was partly masked by the loss due to reluctance pulsation. This will appear from a consideration of Figs. 10, 11 and 12. These figures show that with armature *A* the reluctance pulsations were a maximum with a fairly long gap and a minimum with a very short gap, while with armatures *B* and *C* the reverse is true. Thus the losses in *A* should be relatively large for long gaps (small *q*) and relatively small for short gaps (large *q*.) This is what actually occurs, as shown by Fig. 14, where all the curves correspond to the same mean gap density, (40,000 per sq. in. or 6,200 per sq. cm.), the three groups of curves correspond to the three sets of pole faces, and the three curves of each group to the three armatures.

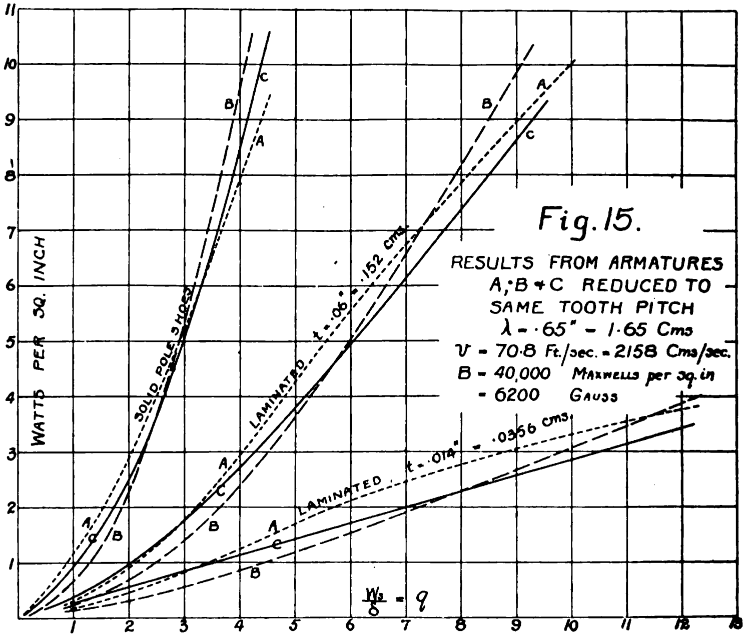

Fig. 15.

RESULTS FROM ARMATURES A, B + C REDUCED TO SAME TOOTH PITCH
$\lambda = .65'' = 1.65$ Cms
$V = 70.8$ Ft./sec. $= 2158$ Cms/sec.
$B = 40,000$ Maxwells per sq. in
$= 6200$ Gauss

While the curves of the three groups are not all perfectly consistent on this point the general tendency is well marked.

Since armature *A* has the largest λ it should have the largest pole-face loss in the case of the solid pole shoes, and the smallest in the case of laminated pole shoes [see equations (6) and (11).] This is borne out roughly by the curves of Fig. 14, if the reluctance pulsation effect be averaged out.

In Fig. 15 the curves of Fig. 14 are reduced to a common value of λ according to equations 6 and 11. This brings out the reluctance pulsation loss still more plainly.

The averaging of the curves of the three armatures, in Fig. 13, averages the effect of reluctance pulsation to a certain extent, since with armature A this loss is larger with long gaps, whereas with armature B and C it is larger with short gaps. But although this averages two armatures against one, in the one the reluctance pulsation comes with long gaps where the true pole-face loss is very small and the percent effect is thus relatively large; in fact it probably more than overbalances the other two armatures in the cases of laminated pole shoes, as indicated by the q exponents.

Effect of laminating pole shoes. The theoretical ratio of solid-pole shoe loss to laminated-pole shoe loss, other things being equal is, (see equation 9) $K = a\,2\,t/\lambda$ where a is a constant slightly greater than one, t the thickness of the laminations. and λ the tooth pitch. Take 1.25 as an approximate value of a; then the ratio is, $1.25\,\frac{2\,t}{\lambda}$. Take a value of λ equal to the average for the three armatures; it is $\lambda = 0.67$. Then for the two thicknesses of laminations employed $K_{0.014} = 0.052$ and $K_{0.06} = 0.224$. The observed average values of these ratios taken from the average curves of Fig. 13 are $K_{0.014} = 0.11$ and $K_{0.06} = 0.278$. The apparent discrepancy is undoubtedly largely due to the imperfect insulation of the laminations; in fact this was practically demonstrated by the following experiment. After the last regular test with the 0.014 in. laminated pole shoes, the bolts were loosened a little, when it was found that the loss was reduced to 70 per cent of its previous value, which materially closes the gap between the observed and the calculated ratio. This loosening would have been carried further, but owing to the manner of supporting the laminated pole shoes it was not considered advisable. They were still tight enough to hold the shoes together firmly when supported by two half-inch screws tapped directly into the back side of the laminations.

Another factor which contributes considerably to this discrepancy is the reluctance-pulsation loss which adds a much larger percentage effect to the laminated-shoe losses than to those of the solid shoes.

A probable change in μ and ρ from the solid to laminated may also account for a part of the discrepancy.

It is thus reasonable to assume that with perfect insulation between the laminæ and with the reluctance-pulsation loss eliminated, the calculated losses would check very closely with the observed losses. The greater discrepancy in the case of the thin laminations is due to the much greater number of partly insulating surfaces, and to the greater percentage effect of the reluctance pulsation loss.

Additional pole-face losses. There are other losses which sometimes add to those here measured for the laminated pole shoes; they are chiefly due to transverse rivets and to the large heads of flat-head screws sometimes used to hold on the laminated shoes.

Except in the case of reluctance pulsations, the rivets do not contribute much to the total loss, owing to the very slight penetration of the tooth flux waves, (about 0.03 in. or 0.04 in.).

The large screw heads do, however, make a considerable addition; for example, the pole shoes which originally accompanied the machine under test had screw heads which occupied 7 per cent of the pole-face area. These pole shoes were of 0.06 in. laminations, so that taking the experimental ratio above, the screw heads would add about 30 per cent to the pole-face loss. With 0.014 in. laminations well insulated the same screw heads would add about 100 per cent to the loss.

Minimum air-gap. Owing to the numerous variables involved, it is impossible to make any general rule as to the smallest allowable air-gap or the largest allowable value of q, but a careful study of the curves of Fig. 13 together with equations 6 and 11 should make possible a reasonably intelligent decision for any given case.

Comparison of theoretical with observed results. Although the numerical coefficients and exponents in the wholly theoretical equations cannot be expected to give satisfactory practical results in a problem involving so many complex relations, it may be interesting nevertheless to see how closely these results compare to those observed. The observed results for comparison are obtained by averaging the three curves in each set of Fig. 15. In making the theoretical computations k^2 is taken from the curve of Fig. 8; μ is taken as 2000 and ρ as 1.5×10^3 in absolute electromagnetic units; a in equation 11 is taken as 1.25; $\lambda = 0.682$ in. = 1.73 cm. $v = 70.8$ ft. per sec. = 2160 cm. per sec.

In Fig. 16 are plotted the three averaged observed curves, one for each set of pole shoes and all for the same density, 40,000 per square inch. The light line curves were computed from equations 6 and 11 and the data assumed above, for the same conditions.

It is thus evident that when the imperfect insulation of the laminations and the reluctance pulsation loss are taken into account, and when it is remembered that μ and ρ are not at all accurately known, the theoretical results compare very well with those observed.

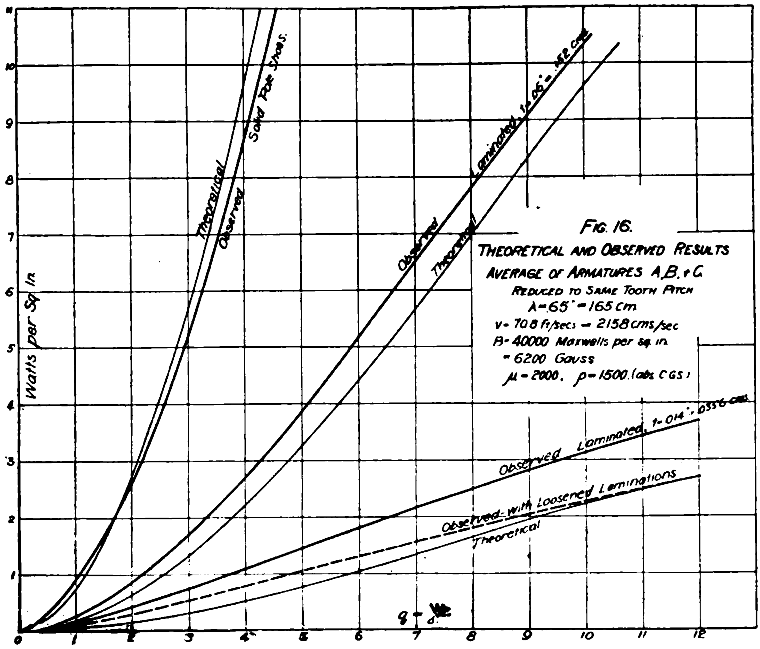

FIG. 16.
THEORETICAL AND OBSERVED RESULTS
AVERAGE OF ARMATURES A, B, & C
REDUCED TO SAME TOOTH PITCH
$\lambda = .65'' = 1.65$ cm
$v = 70.8$ ft/secs $= 2158$ cms/sec
$B = 40000$ Maxwells per sq. in.
$= 6200$ Gauss
$\mu = 2000$, $\rho = 1500$ (abs. CGS)

Distortion due to armature reaction. All the results thus far obtained apply only to no-load conditions, but the effect of armature distortion is easily taken into account. Given the dimensions and data of the machine, lay out the full-load flux distribution and compute the *form-factor* (ratio of root mean power to average value) of this curve. Multiply the no-load loss by this *form-factor*.

Design considerations. It will be interesting now to compare the watts lost per unit of pole-face area with the useful watts developed in the equivalent armature area, as their ratio will give the per cent pole-face loss.

Let $\triangle$ = the peripheral armature current (ampere conductors per inch of periphery),

v = peripheral velocity of armature in ft. per sec.

B = mean pole-face density maxwells per sq. inch.

Then the useful watts developed per sq. in. of pole face is

$$P_0'' = 12\, v \triangle B\, 10^{-8}$$

Taking the pole face watts per sq. in. from equation 12*a* for solid pole shoes:

$$P'' = 12.9 \times 10^{-4} \left(\frac{v}{10}\right)^{1.55} \left(\frac{B}{10^4}\right)^{2.5} q^{1.88} \sqrt{\lambda}$$

$$q_{pf} = \frac{P''}{P_0''} = \frac{1.07}{10^3} \left(\frac{v}{10}\right)^{.55} \left(\frac{B}{10^4}\right)^{1.5} \left(\frac{\triangle}{100}\right)^{-1} q^{1.88} \sqrt{\lambda}$$

This shows clearly what factors determine the per cent of pole-face loss, and makes it possible to consider intelligently the question of pole-face lamination as a rational part of design.

For example, take $v = 50$, $B = 40{,}000$, $\triangle = 400$, and $\lambda = 0.7''$ then in order to keep q_{pf} within one per cent it is necessary to keep q below 1.6 for solid pole shoes. For 0.06 inch laminated pole shoes q could be increased to 3.1, and for 0.014 inch laminated pole shoes q could be as large as 5.9 without raising q_{pf} above one per cent. For other values of B, v, $\triangle$, and λ these percentages would change somewhat.

It is obvious from the above results that it is quite possible to get values of q_{pf} considerably above one per cent without exceeding ordinary proportions.

Although there are other considerations than that of pole face loss which frequently control the choice of the air gap and of the pole shoe type, it is hoped that the experimental results and analysis above presented may help toward a more rational consideration of these questions.

A paper presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., July 1, 1909.

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(*Subject to final revision for the Transactions.*)

THE TRAINING OF NON-TECHNICAL MEN

BY C. R. DOOLEY

In electrical engineering the proper and efficient arrangement of iron, copper, and insulation, is only a part of the problem. The proper and efficient arrangement of brain and muscle providing for higher individual efficiency of all classes of men who are to carry on the business of the future, is the fundamental part of the engineering problem and therefore should merit the most careful consideration of an engineering society such as the Institute.

This part of the problem should not be left entirely to the engineering colleges, for they are unable to arrive at a complete solution. In the first place the engineering schools supply a very small number, perhaps less than one per cent, of the men required to carry on the business. In the second place their graduates are practically all led along one line to a single level. There are few if any college courses in salesmanship, foremanship, shop management, etc. Few colleges expect their graduates to become skilled mechanics, tool designers, or even draftsmen. The manufacturer of electrical apparatus needs a few highly trained men to carry on scientific research, but he just as greatly needs laborers, skilled mechanics, efficient clerks, shop directors, inspectors of materials and hundreds of tradesmen, and all of these need training to develop the best that is in each man for the direct benefit of his employer.

The need of special and general training for all classes of men instead of for one class, is strikingly emphasized by the great number of commercial enterprises that are providing for their men systematic training in a combined scientific and practical way.

The educational activities in the vicinity of the Westinghouse interests at East Pittsburgh divide themselves into two general classes: 1. The training of the graduates of engineering schools. 2. The training of non-technical men. It is the purpose of this paper to describe the work that is being carried on along the latter line.

The training of non-technical men is further divided into two distinct lines: 1. The apprenticeship system, which includes a certain amount of systematic class instruction given during working hours. 2. The night school, where attendance is purely voluntary. Both of these have a place in the training of non-technical men.

The situation. The present scarcity of skilled workmen is a matter of great moment to the manufacturer. He is vitally concerned in plans for the future that will insure men of all-around skill in their respective lines. He may rely upon the engineering schools for the majority of his managers, but who will broaden and train his workmen? The present highly specialized labor is proving inadequate in many shops for two reasons: 1. The dwarfing of the ambitions of the men. 2. The almost total absence of old-time all-round mechanics, which restricts the transfering of workmen from one section of a shop to another.

This is the age of specialization, but the extreme specialization that is seen on every hand will kill the best impulses of human nature and ruin our national endeavor. Almost every machine shop in the country is filled with special machinists, or rather machine specialists; in short, machine-men. Man is not a machine. To allow him to become a mechanical producer instead of a thinking producer, is not only wrong ethically but is rapidly being recognized as wrong economically.

That which is best for the individual is best for the concern for which he works. The managements of large concerns are eagerly looking forward to the increase in the productive power of the workmen, and will willingly pay for it accordingly. The question of the future is not how to get a man to do a day's work for the least pay, but how to get the most efficient work out of the man, increasing his pay in proportion.

The apprenticeship system. The development of the boy and not " shop production " should be the watchword of the apprenticeship department of every company. At the works of the electric company already referred to, the apprenticeship department is being developed in a most systematic and careful manner, the first vice-president of the company taking an active part. In this establishment the work of the apprentices is divided into two departments: 1. The shop. 2. The classroom.

In the shop the plan is to devote a certain section to the apprentices. This section is fitted with a complete equipment to furnish shop-practice in all branches of the machinists' trade. In the shop the boys are under the guidance of shop instructors having the rank of foremen. These instructors are all-around mechanics taken from the shop organization and chosen for their interest in young men as well as for their skill as workman. The boys are moved from machine to machine, from operation to operation, in systematic order and are at all times under the guidance of the shop instructors. The boys remain in this section approximately two years. The latter half of their course is spent in the various sections of the shop. During this period they do not have the direct attention of the shop instructors but are under the care of the apprenticeship department and are transferred about the works as is deemed best for the individual boy, according to his natural ability.

In the classroom the instruction is provided on the company's time, and is conducted throughout the four years of the course. This work is a part of the daily schedule, and the apprentices report to the classroom as systematically as to their shop foremen. Special rooms inside the works have been fitted with suitable tables, desks, blackboards, etc., much the same as any ordinary schoolroom. However, the atmosphere is hardly that of a schoolroom, but rather that of a class where the boys are given problems and explanations concerning the things with which they work every day, instead of problems in abstract mathematics. In connection with the character of the class work there are three vital points: 1. The scientific principles underlying the subjects must be taught. 2. These scientific principles can best be presented through the working of practical problems dealing with the things of the boy's everyday life. This will hold his interest. 3. The same problem must teach him certain facts and specific knowledge concerning the things with which he is working, such as weights, costs, and strength of materials, gear speeds, pulley and belt speeds, etc. In fact, a knowledge of the things with which the problems deal and the facility offered for thinking about these very ordinary things, may be the most valuable feature of this instruction.

As a specific case consider the subject of addition of frac-tions and mixed numbers. Instead of an abstract group of such quantities to be added, the boy is given this problem:

> A shaft has two shoulders. The length from one end to the nearest shoulder is $3\frac{7}{8}$ in. The length between shoulders is 1 ft. $4\frac{1}{2}$ in. The length from the second shoulder to the other end is $4\frac{3}{4}$ in. Allowing $\frac{3}{16}$ in. at each end for finish, what length of stock will be required to make four shafts?

Nor is this type of problem too simple for the average apprentice. Out of a class of 103 beginners, 45 could scarcely add or multiply decimal quantities and knew practically nothing about proportion and percentage.

There is yet another phase of the work without which all else will fail. For want of a better name we call it spirit. It includes loyalty and enthusiasm, not only in the work and the future it holds for the boys, but also in all their daily relations with their fellows—a spirit of service and willingness, confidence in all things and all people, and eternal optimism. This may be illustrated by the following incident: The second week of the operation of the class work included a holiday which happened to come on Monday. One boy in the Monday class complained of his hard luck in losing a period owing to the holiday. Another boy was congratulating himself upon being in the Tuesday class.

At present the class work is scheduled under two general heads: 1. Mechanical drawing. 2. Shop arithmetic. Each of these subjects embraces a certain amount of the general subjects of shop problems, tool construction, tool operation, shop organization, and system, as well as the fundamental science of the subject itself.

The night school. The best organized apprenticeship system, even with its supplemental classroom work, will not satisfy the more ambitious young men. Such men are studying every spare moment; they are taking correspondence courses or are attending night school. They are not satisfied with learning a trade, but have a desire for a broader training leading toward engineering. There is a prevalent feeling that engineering training applies only to college men, that for the 95 per cent of the boys of the country who never finish high school, the problem is one of industrial education with specific training in definite trades. While this is perhaps true in the majority of cases, it is not a foregone conclusion.

A night school is not necessarily a trade school. On the contrary, a night school may do high-grade engineering work, in fact, from some points of view a properly organized night school, or some other form of close coöperation between technical training and commercial practice, may offer the best opportunity for engineering training. One thing that makes for high efficiency in night-school work is the character of the men that pursue it. The schedule of work is necessarily difficult, and hence only the more industrious and ambitious boys will take it up. The very nature of this system is selective in the beginning, but the selection is natural and self-appointed and therefore just. Another thing is the daily contact with the intensely commercial sides of all problems, the theoretical sides of which are explained in the schoolroom. If during four years of the study of theoretical and experimental electricity in the night school, the student is employed during the daytime in a powerhouse, on a wire gang, winding and insulating armatures or assembling switchboards, he will get a type of engineering training that is in great demand.

Six years ago The Casino Technical Night School was started in the vicinity of the manufacturing interests already referred to. Its management is independent of any commercial industry, though its activity is encouraged and fostered by the local organizations, including the public school board, the latter furnishing the housing. In the beginning there were half a dozen teachers and a few dozen students who attended classes in drawing, elementary mathematics, and shop practice. There is now offered an opportunity for systematic study in such fundamentals as: mathematics, mechanical drawing, mechanics, physics, theoretical and applied electricity, chemistry, shop practice in both wood and iron, theoretical and applied steam engineering, etc. There is a faculty of 25 instructors and an enrolment of about 300 students. The growth and development has been along sure and conservative lines and only as rapid as the demand of the students required, and yet in the 6 years the actual number of hours that each student devotes to the entire course have been increased over seven-fold; from two sessions of 40 min. each, on two evenings for a term of 2 years, to three sessions of 60 min. each, on three evenings each week for a term of 4 years.

The instructors are themselves not only versed in the theory of their respective subjects but each is also actively engaged during the day with his subject within the organization of a commercial factory. The advantages in the way of securing exceptionally trained teachers are therefore ideal.

Attendance is voluntary and a small tuition fee is charged. Admission is extended to all regardless of occupation or previous education. The low educational entrance qualifications are cared for by a preparatory department. Practically all of the students are employed in the various shops in this vicinity the regulation 9.75 hr. per day besides attending school 3 hr. on three evenings each week. The schedule of work is such that they cannot possibly keep up without devoting several of the remaining evenings of the week to the preparation of their lessons. Though the school has a vacation period from June to September, yet these men are devoting practically all of their time to study and to work—to the acquisition of scientific knowledge and commercial experience. In addition to this it is a common thing for groups of students to request additional work. During the past year a class of some 15 students meet once a week after school—after 9:15 p.m.—to study English. These men not only did this work in addition to their regular schedule but bore the extra expense necessary to maintain the class.

Perhaps it will be thought, this is too much. But is it any more than the aggressive man in commercial activity is doing and expects to do the balance of his life? Is it not exactly what the 25 instructors are doing? These instructors have their daily routine in shop, testing room, drafting room, and engineering department. The pay for their school work is small, but the work is both interesting and broadening. The relation between students and instructors is ideal—they learn and teach with an absolute mutual confidence and personal interest.

This wholesome spirit finds expression in many ways, notably in the conduct of the classroom where matters of discipline are practically unknown; in class organization, the presidents of the several classes organizing themselves into a student council for the furthering of the interests of the school; and in the general interest shown at commencement time when the year's work is drawn to a close with appropriate exercises comprising orations by members of the graduating class and an address by a prominent engineer or educator, and a dinner which marks the very climax of enthusiasm and loyalty.

Nor has the social side of student life been omitted. The boys have organized a glee club, a mandolin club, a basket-ball team, and a base-ball team. They also edit and publish a small monthly bulletin. These clubs are well organized and would do credit to many a college organization.

The total enrolment just before the financial depression was something over 300. For the year just closed it was approximately 250. In general, 80 per cent of those who enroll complete the term's work. Of the 45 men who have been graduated during the past three years, practically all have been steadily advanced in position and responsibility, and 40 are still with their original employers. While no degree can be given the graduates, the character of their work and the positions held by the men after graduation may warrant the assertion that the Casino school is, if not the first night school, among the first to graduate men in engineering. Some of the graduates are doing high-grade engineering work in the engineering department and in the drafting office of the nearby electrical manufacturing company. Others are successful salesmen and many are doing responsible work in the erection department and in the shop organization.

The engineering night school has a large field of activity. At the start its students possess a clear idea of commercial practice which the newly graduated college student seldom has. This early experience instills an appreciation of the value of time and of the value of scientific training that tends to produce the most efficient student. They have learned several years earlier in life that scientific study and commercial practice not only go hand in hand but that they should continue hand in hand throughout life if the highest achievements are to be attained; that there never comes a time when the one can be laid aside and the other taken up. They also know the importance of the routine of life, that from the office boy to the president, it is the fellow who gets the job done that gets the bigger job to do.

While it is not within the province of a manufacturing concern to provide a liberal education for its men, with the present degree of general education among young boys it is within the principles of good business to provide and maintain a training in those fundamental subjects which will assist in developing skilled mechanics and workmen of higher ideals to carry on the business of the future. Further, a manufacturing concern can well afford to assist and encourage the exceptional young man to as high a technical training as he will take.

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(Subject to final revision for the Transactions.)

ELECTRICITY IN MINES

BY GEO. R. WOOD

Before describing some typical coal-mining plants, with their especial features, the author will outline the ordinary mine development and some of the standard electrical mining equipment.

Assuming that the coal vein lies almost horizontally, with an average dip of, say, 1.5 to 4 or 5 per cent, the main headings or tunnels are driven to the raise where possible, so that grades will favor the loads. At intervals of about 1200 ft., cross-headings or flats are driven at right angles to the mains, and from these, parallel to the mains, are driven room-headings or entries, from 300 to 600 ft. apart. The rooms or chambers from which most of the coal is taken are turned from these entries, and are started in about the same width—10 ft.—as the entries. When in about 20 ft. they are widened out to full width—from 20 to 30 ft. These rooms are driven on about 40-ft. centers, leaving a pillar of coal between them from 10 to 20 ft. thick, to support the roof.

The thickness of coal in the Pittsburgh seam runs from 5 to 7 ft., in the Connellsville basin from 6 to 9 ft., and in central Pennsylvania from 3 to 5 ft. In a completely equipped electrical mine, the coal is undercut by electrical machines, hauled from rooms to cross-headings by small gathering locomotives, and from cross-headings to main tunnels and thence to the tipple by larger locomotives. Electric pumps of various sizes handle the water; electric motors drive the fans which ventilate the mines; and car-hauls, crushers, elevators, and the like, where used, are also driven by motors.

Electrical mine locomotives and machines have been in use for more than 20 years. Originally very crude and expensive to operate, they are now highly developed and satisfactory pieces of apparatus. Some of the first locomotives were made of street-car trucks weighted down. Many were of the single-motor type, with connecting rods or with chain drive. The motors were not enclosed, and the trolley was of the pantagraph type. For a long time the equipment was inadequate, largely on account of the narrow gauge as compared with street-railway work, and also because each locomotive was proportioned for particular service, which afterwards increased as the haul was extended. The equipment was based on about 5.5 h.p. per ton, which will stand an intermittent service fairly well, but is not sufficient for long hauls or on heavy grades where sand is used.

Modern locomotives have usually two series motors, with a total capacity of about 10 h.p. per ton of locomotive weight. These motors are rated at 75 degrees cent. rise in 1 hr., or in some cases are rated for 40-min. service. A rheostatic controller with grid resistance is used, and motors are operated in parallel on heavy pulls and in series for switching. The change is made by a four-point reversing cylinder. In a new controller for heavy work, each point on the controlling cylinder has a double-contact finger and a separate blow-out coil. Arc headlights are largely used.

In many mines it is desired to gather the wagons from rooms to cross-headings by motors. For this service small locomotives weighing from 4 to 6.5 tons are used, and since it is not desirable to have trolley wire in the rooms, these locomotives are provided with cable reels. These reels are arranged automatically to reel out cable when running into rooms, and reel it up again on coming out. The cable is hooked over the entry trolley and supplies current to the locomotives. The reel may be driven by a sprocket chain, through a friction clutch, from the axle of the locomotive or from the shaft of one motor. The reel may also be operated by a coiled spring, if the cable be not too long, or by a small series motor connected permanently in circuit. Where grades are very heavy against the load, a wire-rope reel, with a small independent motor, is sometimes provided. In this case, the locomotive remains at the top of the grade, lowers the empty car by gravity and hauls up the loaded wagon by the wire rope.

Mainline four-wheel locomotives are not often made heavier

than 14 tons, on account of the heavy rail required. When more power is needed, six-wheel, three-motor locomotives are used, of from 15 to 20 tons weight, or two four-wheel locomotives are coupled together with a single four-motor controller, and with the brake rigging operated from one lever. These tandem locomotives are sometimes so arranged as to be easily disconnected and worked separately when desired.

Electric coal-cutters were first of the "cutter-bar" type, in which the "bits" or small chisels were staggered around the surface of a horizontal cylinder, which was rotated and forced under the coal, making an undercut of a width and height equal to the length and diameter, respectively, of the cylinder cutter head. The next type was the chain-breast machine, which is very largely in use at present. This type comprises a stationary rectangular frame and a moveable frame, carrying the motor, gearing and cutter head, travelling within the stationary frame. The cutter head is the base of a long isosceles triangle, around which the chain is driven by a sprocket at the apex. This chain carries a number of cutters or bits, about one-third being uppers, one-third lowers, and one-third centers. The chain is fed forward into and under the coal by a rack-and-pinion feed, the cut being about 4 or 5 in. high and 44 in. wide. Both types of machines, after making a cut to the desired depth, are shifted side-ways; the operation is repeated until the face of the room is undercut completely across, after which the coal is blasted down.

A new type of machine is an electrically driven puncher. This puncher consists of a vertical motor with gearing, and a cylinder and two pistons, one of which is driven by the motor, the other carrying the cutting-tool or pick. The rear piston, driven by the motor, compresses air on its backward stroke, and the front piston, carrying the tool, is forced back by atmospheric pressure. At a certain point the rear piston passes a port which admits the compressed air between the two pistons. As the front piston is free to move, it is driven forward, causing the tool to strike the coal with great force. Should the pick not strike the coal, the blow is absorbed by an air cushion at the front of the cylinder. This machine is mounted on a pair of wheels, like the air puncher, and is operated in substantially the same way.

Another type of under-cutting machine is similar to the chain-breast machine, except that after making the first undercut, instead of withdrawing, moving sideways, and repeating the forward cut, this machine remains under the coal and is drawn sideways across the room, cutting as it goes. This type is especially adapted for cutting wide rooms or long faces, and is called a " long-wall " machine.

Machines have also been designed to cut and load the coal, without blasting. One of these is made up of two discs or cutting wheels about 4 ft. in diameter carrying bits in the periphery, mounted side by side and rotated in opposite directions. These are fed into the coal and undercut it, carrying the cuttings to the center, where a conveyor chain picks them up and feeds them back into a car. At the same time, two puncher machines, mounted above the wheels and one at each side, on swivels, are used to break down the coal as it is undercut, the cutter wheels throwing the coal to the center whence it is carried back by the conveyor. This machine as first designed is operated by compressed air.

Another machine has a double cutter head, like two standard chain machines, one above the other. The double head is swung in a vertical plane, describing an arc of about 180 degrees, like a steam shovel, except that the cutting is done on the downward stroke. This machine cuts the entire vein into fine slack, which is preferable for coking.

Electric mine pumping does not differ essentially from power pumping on the surface, except that the water is usually acid, and that grit and fine coal must often be handled. In the geared-type plunger pumps, the valve lift is increased to allow the passage of fine coal, etc., and the cylinders, plungers, valve seats and stuffing boxes are made of acid-resisting material. In some extreme cases cement-lined pumps with wooden plungers are used, or the entire pump is wood-lined. Where the water is not too strongly acid, and other conditions are favorable, turbine pumps are used, eliminating valves, packing, gears, etc. Rotary pumps of new design are also coming into use where the water does not contain much grit.

One of the first electrical mining plants in the Pittsburg district was that at Grindstone, near Brownsville, Pa. The generator was a bipolar machine of about 60 kw., driven by a Corliss engine through a countershaft. It is still in daily operation. Cutter-bar mining machines were operated.

The two largest plants at that period were those at Essen, near Carnegie, and Scott Haven, above McKeesport, both of which are now operated by the Pittsburgh Coal Company. The Essen plant supplied two mines, and consisted of three bipolar, 250-volt, 150-kw. generators, belt-driven. A number of mining locomotives were used, these having but one motor, carried lengthwise in the locomotive frame, with bevel gears at each end. On account of this positive connection to all driven wheels, and also on account of the steel-tired wheels, these locomotives had a very high draw-bar pull, but they were expensive to operate on account of the difficulty of holding the bevel gearing in line.

The Scott Haven plant, installed in 1895, supplied four mines, and consisted of four belted, 550-volt, 100-kw., four-pole generators. The switchboard was a skeleton oak frame, with round copper bus-bars, the switches being front-connected. On account of the high potential, a metallic circuit was provided for the mining machines as being safer for the men, but this circuit quickly became grounded in the mines. All the apparatus was later put on a grounded circuit with rail return.

The locomotives in the Scott Haven plant were of the two-motor type and mechanically of modern design. The motors were of about 23-h.p. rating on 10-ton locomotives. The armatures were cross-connected and were very difficult to rewind. These motors were replaced in 1898 by 35-h.p. motors for narrow gauge use, originally designed, the author believes, for the Boston Elevated Railway. One of these locomotives has still in service the motor installed in 1898, the armature never having been taken out.

The installation at Scott Haven included some of the earliest motor-driven fans and pumps. Practically all of these are still in use.

One of the first direct-connected plants was installed in 1897 at Moon Run, about 5 miles West of McKees Rocks. This plant was first used for haulage alone, and included one 165-kw., 250-volt generator, driven at 240 rev. per min. by a center-crank engine. Another unit was installed later with a side-crank engine, but before this was in place the center-crank engine shaft broke in the disc. It was operated for several weeks after breaking in two, until the other unit could be started.

One of the first alternating-current central plants for coal-mining purposes was installed in 1902 at Gary, W. Va. This plant first contained two 400-kw., 6600-volt, 25-cycle generators, driven by twin simple engines with independent governors.

The exciting equipment consisted of one 25-kw. vertical engine-driven unit and one 25-kw. generator direct-driven by a 40-h.p. induction motor at 720 rev. per min. All oil switches were in brick cells back of the switchboard, with remote manual control, the feeder switches being of the automatic overload release type with time limit relay. The generator switches were non-automatic.

The longest transmission was originally 3 miles. Three substations were built, each containing one 150-kw., 275-volt converter with step-down transformers and the usual switchboard equipment. Each sub-station also contained step-down transformers for induction motors at tipples, etc. Direct current from the converters was used for haulage only, supplying main-line and gathering locomotives of the cable-reel type, and the larry equipments for the coke ovens. These larry equipments included one motor with a reversing controller, resistance and trolley, and the motors were duplicates of those on the smaller locomotives. Each larry could haul one trailer.

Induction motors are used on single-stage, two-stage, four stage and five-stage turbine pumps, for coke oven supply; on crushers in sizes of 75, 200, 300 and 400 h.p. at the tipples; on mine fans, for which purpose two-speed, changeable-pole, 100-h.p. and 150-h.p. motors are used; for driving deep-well pumps and small compressors for air lift, with silent-chain drive; and for driving picking tables, car hauls, conveyers, etc. at tipples.

This plant was later increased by adding two 750-kw., 6600-volt generators, driven by cross-compound Corliss engines at 125 rev. per min. At the same time the original twin simple engines on the smaller units were changed to cross-compound, giving better regulation and economy. Within the past year one 1000-kw. steam turbine on 140 lb. pressure has been added, also one 1000-kw. low-pressure turbine, using exhaust steam from the engines. Condenser equipment, including three large cooling towers, has been provided for the turbines.

Nine sub-stations are now in operation, and three 500-kw. step-up transformers, 6600 to 22,000 volts, have been installed for supplying mines to be opened about 12 or 15 miles distant.

A very economical plant has been installed near Fairchance, Pa., utilizing in the boilers the waste heat from the coke ovens. A large flue is built back of 100 bank ovens, with smaller flues connecting each oven, and a boiler plant is located at the center of each section of 50 ovens. Thus each boiler plant draws from 25 ovens each way, making a travel of about 350 ft. for the hot gases. The engine room is half way between the boiler plants, and contains four 400-kw., 2300-volt, 25-cycles, three-phase generators, driven by cross-compound engines. By means of five sub-stations this plant now supplies seven works, operating locomotives, larry equipments, car hauls, conveyers, fans, pumps and coke-drawing machines. Up to the present time it has been found necessary to operate but one boiler plant, but extensions are under way which will absorb the entire capacity of the plant, one of the additions being a 1000-cu. ft., 1000-lb. motor-driven compressor for supplying air locomotives in a gaseous mine. When the demand for power increases, it is expected to install a low-pressure turbine with condensers, which would give about 1000-kw. additional when operating three engine units.

At Ellsworth, Pa. it was expected ultimately to install an alternating-current central station, and belt-driven synchronous converters were installed for temporary use as three-wire direct-current generators. A neutral was obtained from the collector rings through the secondaries of small 200-volt transformers, and this neutral was permanently grounded to the mine tracks. Locomotives, machines, and pumps were operated at 275 volts between either main lead and the track, the load being balanced as nearly as possible, while outside motors, on fans, etc. are connected across 550 volts. It was found that straight star connections to the neutral from the collector ring through transformers would not work, as the converters bucked badly until interconnections were made to neutralize the flux in the transformers due to unbalanced direct current. It was also clearly demonstrated that the old style converters are much better adapted for use as direct-current generators than the modern design. The first ones installed were built 7 or 8 years ago and operated well with proper attention. One or two new ones could not be operated successfully at more than one-half rated capacity.

Three-wire, direct-current plants are also in operation in West Virginia, using railway type generators, with derived neutral through balancing transformers. One of these plants, at Minden, W. Va., operates three 300-kw., 600-300-volt generators, driven by cross-compound engines, and supplies four mines. The apparatus in use includes 20 locomotives, 16 machines, 21 pumps and 14 fan, car-haul, and miscellaneous motors.

The three-wire system has the advantage of being less dangerous than that using 550 volts pressure; the return or bonding need not be so good, and motors, etc. stand up better. The two voltages are also useful for variable-speed requirements. It is objected to on account of the care required in balancing the circuits. As a transmission problem, it is, with perfect balance, a 600-volt metallic circuit, and therefore requires just twice the copper—neglecting the difference in bonding—as a 600-volt, grounded-return system, or half the copper as compared with a two-wire, 300-volt grounded system. The balancing is most effective when a large number of small units are operated. The unbalanced current at Minden rarely exceeds 15 per cent.

In Woodward, Alabama, a plant has been installed at the furnaces of the Woodward Iron Company, taking steam from the furnace boiler plant, normally fired by blast-furnace gas. The plant includes three 400-kw., 3500-volt, 25-cycle, three-phase generators, with cross-compound engines. At or near the furnaces two two-stage turbine pumps, delivering 3000 gal. per minute each against a 135-ft. head, are operated for furnace use, while two 100-kw. motor-generator sets supply 250-volt direct current to shop motors, small locomotives handling ore wagons, and a travelling crane handling hot iron on the casting floor.

At No. 1 coal mine, about 2.5 miles away, the current is taken underground in a three-conductor, varnished-cloth insulated, steel-armored cable. Four thousand feet inside are two 700-gal. triplex pumps chain-driven by two 150-h.p., 3300-volt, induction motors and working against a 550-ft head. A few thousand feet farther in is an endless rope haulage, chain-driven by a variable-speed, 3300-volt motor, running at 200-480 rev. per min., with a controller and secondary resistance. About two miles from the pit mouth is an underground sub-station, containing one 200-kw. converter with step-down transformers, etc., supplying 275-volt current to mine locomotives. A number of small triplex pumps, operated by 440-volt induction motors, are also in use.

At No. 2 coal mine, about two-thirds of a mile farther from the power plant, current is taken underground approximately two miles to a duplicate sub-station, also supplying locomotives, and up an air shaft to a 50-h.p., 3300-volt motor driving a mine fan. On account of the frequent labor troubles in that district, it was not advisable to take any power overhead, except along the railroad to the coal mines, where the line could be patrolled.

The plant is now being enlarged to provide power to the ore mines, three miles from the plant in another direction, to operate hoists, crushers, pumps, and air compressors for rock drills.

The six 150-h.p., 3300-volt motors on turbine pumps, triplex pumps, and motor-generator sets are duplicates. The underground cable is suspended from a messenger wire, with frequent loops for expansion and repair. There have been several rock-falls on the cable, most of which have caused short-circuits, but repairs are easily made. The armor is protected against corrosion by a layer of jute and asphalt, but the miners have cut a good deal of this off for kindling to start fires. They also stole about 40 gallons of oil out of the substation transformers one night, for use in their lamps.

These mines go in on a slope of about 20 per cent for the first mile, after which the vein flattens out. There is only about 4 ft. of headroom. A good deal of the underground apparatus was skidded down on the track rails.

At Ehrenfeld, near Johnstown, is a plant in which belt-driven converters were first used for generators, supplying an underground substation through step-up transformers from 165 to 5600 volts. This substation contained, besides the necessary step-down transformers, one 250-kw., 275-volt converter, operating on the trolley in parallel with the direct-current side of the double-current generators. This was the first alternating-current plant operating underground substations. Larger direct-connected generators have since been installed. It was the intention to use the original generators as converters later.

At Yatesboro, Pa., there is a successful installation, operating a number of motor-driven compressors, fans and sub-stations. The station equipment includes two 1500-kw., 60-cycle turbine units, generating three-phase current at 6600 volts. In two substations are installed 300-kw., 550-volt converters running at 900 rev. per min. and in a third a motor-generator set, with an induction motor driving a 300-kw., 550-volt generator. Three motor-driven fans are in use at different mines, one with a 250-h.p. motor, belt-driven, one with a 250-h.p. motor and silent-chain drive, and a third with a 400-h.p. motor direct-connected through a flexible coupling. There are also, at the various mines, eleven 1400-cu. ft. duplex compressors, belt-driven by 250-h.p., 6600-volt induction motors. One interesting feature of this plant is that these high-tension induction motors are all started by throwing directly on the line.

At Windber, Pa., there have been operating, until this year, eight direct-current power plants supplying 12 mines. Two of these plants, those at No. 36 and No. 40 mines, are efficient installations with cross-compound condensing Corliss units, water-tube boilers, etc., but the range of distribution was such that the loss in transmission overcame the efficiency in the plants.

In most of the mines locomotives only were operated, at 550 volts, and the transmission was from 1.5 to 2.5 miles. Compressed-air " puncher-type " mining machines and compressed-air pumps were used, with steam engine-driven fans. It was decided to centralize the power, to do away with all the direct-current power plants, except No. 36 and No. 40, and to limit their field to a radius not exceeding 1.5 miles. The boilers from some of the dismantled steam plants have been assembled and a plant installed at No. 35 mine, in nearly the center of the field. The equipment includes one 400-kw., 6600-volt, three-phase, 25-cycle generator, driven by a cross-compound engine, and two 1000-kw. steam-turbine units to operate at 140 lb. pressure and 1500 rev. per min. One additional turbine unit, probably of 3000-kw. capacity, will be installed early next year.

The 400-kw. engine-driven unit, with two 200-kw. converters, was purchased some years ago. These converters with one additional, will be installed at No. 38 mine and also supply No. 39. At No. 33 mine and also to supply the front end of No. 34, will be located two 150-kw., belted-type, 550-volt generators, formerly used at No. 30, now to be direct driven by 225-h.p., 6,600-volt synchronous motors at 500 rev. per min. In this substation will also be installed one 1800-cu. ft., 2-stage air compressor, direct-driven by one 300-h.p., 6600-volt, synchronous motor at 187 rev. per min. In a substation at the back end of No. 34 mine, also supplying No. 31 mine, will be located one 300-kw. converter and two direct-driven 1800 cu. ft., 2-stage compressors.

At No. 41 mine electric puncher machines are supplied with 250-volt current from a 100-kw. generator driven by a 150-h.p. 440-volt induction motor at 750 rev. per min.

At No. 42 mine two 300-kw., 550-volt converters are installed, to operate locomotives in two drifts, one in each vein of coal, and also to feed into the back end of No. 36.

At No. 35 shaft, two miles back from the pit mouth is located a large fan to ventilate No. 35 and parts of No. 36 and No. 40. This fan will be driven by a 400-h.p., variable-speed, 6600-volt motor, direct-connected through flexible coupling, to operate at 200 to 285 rev. per min. A substation here contains two 300-kw. converters, with space reserved for one more, also six 150-kw. transformers, with a 6600-440-volt ratio supplying two large pumps at the shaft bottom. A drainage level was located across mines Nos. 37, 40, 35, 36 and 42, all the water above which will flow by gravity to this shaft. Here will be placed two two-stage turbine pumps, each of 4000-gal. capacity per minute against a 330-ft head, and each will be driven by a 500-h.p., 440-volt induction motor at 730 rev. per min. These pumps will replace over 70 compressed-air and steam pumps.

A sub-station will be located at the rear end of No. 37 mine, and contain one 300-kw. converter, and later one motor-driven compressor. This converter will work in parallel with No. 40 direct-current plant, supplying the outside haulage, etc.

An induction motor has been designed for the electric coal puncher, or " pneumelectric " machine, and it is expected, if this proves a success, to replace the compressed-air punchers wherever found practicable. On account of the large investment in machines, pipe, etc. some mines will still be operated by air, as No. 33, 34, 31, 37 and 40, and wherever necessary for best economy motor-driven compressors will be located near the work, displacing steam-driven machines.

The output of these mines is normally about 18,000 tons per day. The cost per ton has been slowly but steadily increasing from year to year, as the mines advanced, and transmission lines and water lines lengthened. It is expected to increase this output as desired to over 20,000 tons per day, and to reduce the cost at least 6 cents per ton. This cost should then increase but very slightly for probably the next 5 or 10 years.

The cost of the electrical equipment, including foundations, buildings and installation, will approximate $250,000, and the total cost of improvements, such as shafts, drainage tunnels, etc., will amount to about $600,000.

DISCUSSION ON "ELECTRICITY IN MINES." PITTSBURG SECTION, NOVEMBER 10, 1908.

(Subject to final revision for the Transactions.)

F. L. Sessions: I should like to suggest, what is not entirely original, a basis for the rating of mine locomotives as follows: the motor capacity shall be equal to a stated horse power per ton of locomotive weight per mile per hour at a stated speed in miles per hour, at 75 degrees cent. rise of motor temperature as measured by thermometer after a 1-hr. run.

Or, as an alternative which will refer strictly to the locomotive performance at the draw-bar: the rating of an electric mine locomotive shall be based upon the horse power per ton of locomotive weight per mile per hour at a given speed in miles per hour developed at the draw-bar continuously for an hour, with a rise in temperature of any part of the motors of 75 degrees cent.

W. A. Thomas: The exhaust-steam turbine will be of considerable importance in the near future. A number of plants have been equipped, and many more low-pressure turbines might advantageously be installed where the exhaust steam from reciprocating engines is being wasted. In the case of one coal company, since putting in exhaust-steam turbines 1,000 kw. have been recovered on four units, whereas formerly not more than 200 kw. in heating value were obtained from the exhaust of the engines. This economy is bound to become a marked feature in general work as well as in coal-mining operations.

The standard of laws for the use of electricity in mines, that has been considered in the establishment of laws in Pennsylvania is similar to that established in New South Wales. Electrical men who are associated with mining operations should make themselves familiar with these laws.

Probably one-third of the restrictions and special limitations in the New South Wales laws are on account of defective insulation on the wires, and as good insulation is used there as can be obtained in this country. In this country it is usually considered that up to 600 volts the wires should be left bare. In establishing rules in this country I believe it will eventually be decided that bare wires should be used and that we should not trust to insulation.

I agree fully with Mr. Sessions in his ideas on standard ratings. I think that concerted effort should be made on the part of the manufacturers to get mining men who are interested in electrical matters to comprehend more fully what an electrical rating is, and then come to a common basis, as it is confusing to an operator if he is not acquainted with these matters.

H. W. Fisher: The destruction of the lead covering of cables by acids in mines has been repeatedly brought to the attention of the manufacturer of cables. At present we are experimenting with a form of cable which is protected by the use of a high melting compound which is practically acid proof. In making this cable the strand is first coated with the compound, so as to prevent moisture from entering the cable along the strand in case the ends are not especially well protected. Then varnished cloth is applied to about the necessary thickness for the voltage in question, after which a layer of this special compound is applied, then one or two layers more of varnished cloth, and over these the usual braids.

We also make a rubber-insulated cable which is finished with a layer of special black compound and varnished cloth and braid as above specified. These forms of cables have only recently been put on the market, but sufficient time has not elapsed for us to know definitely if they are giving satisfaction.

DISCUSSION ON "CONDENSER TYPE OF INSULATION FOR HIGH-TENSION TERMINALS," AND "HIGH-VOLTAGE TRANSFORMERS AND PROTECTIVE AND CONTROLLING APPARATUS FOR OUTDOOR INSTALLATION." NEW YORK, APRIL 9, 1909.

(*Subject to final revision for the Transactions.*)

W. S. Moody: Some years ago I attempted to build leads such as described by Mr. Reynders. I found that the difficulties encountered without the special facilities which have evidently been developed for building the lead before us, made it virtually impossible to gain anything by using this construction.

There is one feature of such a lead that requires more or better insulating material when the condenser cylinders are introduced than when they are not. With the condenser plates in place, every weak spot in the insulation is in series with every other weak spot, whereas a lead covered entirely with insulating material is not weakened greatly by any one of its weak spots, because this weak spot will not ordinarily, by the mere law of probabilities, be in series with any other weak spot. It is possible then that the use of condenser plates in such an insulation, and notwithstanding the better distribution of internal strain, will make a lead no more and perhaps less capable of withstanding a given strain than if the condenser plates were not used. But this may be no serious objection, for, as Mr. Reynders says, the problem of obtaining sufficient insulation to withstand the puncture is not difficult.

It would seem, therefore, that by far the greatest value to be obtained from this construction is in the equalization of the strain along the exterior surface of the leads. There would seem to be no question that the practically equal distribution of strain that can be and has been obtained in the lead shown us does require the minimum length of lead to withstand a given voltage, provided one confines himself to a plain cylindrical or conical surface for the exposed part of the terminal.

My rather limited trial of this form of insulation was sufficient to convince me that such a lead would be a difficult one to produce under ordinary manufacturing conditions, and that it would be, when completed, rather a delicate affair mechanically. I therefore turned my attention to other forms, which have given very satisfactory service on operating pressures all the way from 100,000 to 500,000 volts.

Nearly 8 years ago, when only the most courageous were beginning to think of 60,000 volts as a commercial possibility, I gave to my assistant, J. J. Frank, the problem of building a 500,000-volt transformer. In the preliminary tests leading up to the design of this transformer, it was found when an air or oil space was under electrostatic stress that the introduction into this space of several sheets of metal lowered the voltage required to puncture; whereas the introduction of several sheets of insulating material—consisting of something that was inferior to oil or even air as insulation—markedly increased the voltage required to puncture. It was therefore decided to subdivide the oil--which was chosen as the only material to provide satisfactorily against puncture for a pressure such as 500,000 volts—by insulation cylinders rather than by metal cylinders.

In attacking the problem of providing surface insulation for 500,000 volts, it was clearly apparent that the 15 to 18 ft. of such surface that would be required could hardly be attained in a straight line, but that some form of irregular surface, such as that used in line insulators, must be resorted to. These ideas, combined, resulted in the production of a lead about 16 in. in diameter where it passed through its support, and about 80 in. long each side of this support. This lead has been in most frequent use for 6 years in connection with all sorts of special testing, and has been subjected to from 300,000 to 650,000 volts.

This lead consists of a tube of low-grade insulating material, tapering in diameter both ways from the point at which the lead is to be supported, the tube being filled with a high-grade insulating liquid or semi-liquid compound, such as oil or asphaltum. The tube is made up of sections telescoping into each other slightly, and between each section are rings of similar material projecting beyond the sections to give very great leakage distance on the surface. In the later forms of these sections the projecting part is made integral with the section, so that the section has the general appearance of the petticoat of a line insulator. After a suitable cement has been placed on them, all the sections are drawn tightly together by the conductor itself, which is a heavy rod or tube. The space between the walls of the tube and the conductor is divided into several sections by thin cylinders of insulating material. The entire air space in the lead is then filled with the insulating compound.

A lead used for 100,000-volt transformers is regularly tested at 200,000 volts, some of the leads having withstood 225,000 volts for 15 or 20 min. The dimensions of one of these leads are, diameter, 7.5 in., length, 39 in.

It would seem, therefore, that the very long leakage surface, which is so easily attained in this construction, enables one to reduce materially the length of the lead to stand a given strain as compared with a lead without the irregular surface but with a most perfect distribution of the strain, and that no excessive diameter has to be used at the point where the lead passes through the cover. My experience is that there is little difficulty in providing space for leads of quite large diameters in such sizes of transformers as are ordinarily built for 100,000 volts and more. It is desirable though to keep the length of the lead above the cover as small as possible, as the transformer is usually the tallest piece of apparatus that goes into the station, and its over-all height has, therefore, often a direct effect on the cost of the station.

It is evident that one or more of the internal insulating cylinders in this construction could be metallic; and if they were metallic the lead could be made to have a somewhat better distribution of the external strains. But as the lead is now little longer than is necessary to provide a safe factor in the air distance from terminal to cover, only a slight reduction of length could result.

It seems to me that if the principle of distributing the strain on a terminal by a condenser is to be applied extensively, a lead of robust mechanical construction with one, or, at the most, two or three, condenser cylinders is more likely of ultimate adoption than one requiring the refinements of manufacturing conditions and delicate handling required by the lead described in the paper. Moreover, for indoor use at least, it will usually be desirable to use a form of lead whose length from terminal to cover is not greatly in excess of the distance which the test voltage will jump in air.

The problem of having a transformer outdoors is not a new one, of course. All the earlier transformers were placed outdoors as are the present small transformers. The only new points to consider in building large units, as Mr. Randall has said, are in taking extra precautions that the transformer be weather-proof, and providing easy means of repairs.

With reference to their being weather-proof, I believe that in the large units, involving so much money, we should never depend on the joints being absolutely tight, because the best made joint is liable to loosen up. I think it would be very much better if the transformer were kept under a slight internal pressure all the time, so that when leaks developed they would be outward rather than inward. A little gas generator could maintain a pressure on top of the transformer, or an auxiliary tank of oil could be used to keep a slight head of oil on the transformer all the time.

There is one difficulty with transformers installed in this way; that is, the insulating qualities of oil at low temperatures. Oil, when frozen, is ordinarily about as good an insulator as when liquid, but just about the freezing point, especially after it has been frozen, its insulating qualities are greatly reduced. It may be necessary to use some new oil, or that some new method of refining oil be worked out before we can be sure that the transformer that is left outdoors in a cold climate may not have its insulating qualities greatly reduced at low temperatures.

Percy H. Thomas: As Mr. Randall has stated, the crux of the matter of the outdoor station is the advantage in cost of plant; in most other respects the arrangement is, perhaps, disadvantageous. Perhaps it is easier to summarize the difficulties than the advantages. Mr. Randall has well pointed out the chief causes and annoyances of failure; the extra operating expense; the difficulty of inspection, which is really a very important one; and the matter of being able to open the transformers and switches at any time. If the climate is at all bad, I think it would preclude the outdoor apparatus. In any such climate as that of New York where there is much sleet and snow and where one would not always open the apparatus and look at it, I think there would be much difficulty experienced.

The question of repairs is also important. Mr. Randall suggested a special repair house. Would not the cost of a repair house justify the additional cost of putting the whole apparatus in a building? The necessity of working in a cold or exposed place makes any repairs much more difficult, and much slower in their execution. These facts must be clearly borne in mind in weighing any saving in first cost that can be made by omitting the building.

I will call attention to the danger of electrolytic arresters freezing. They seem necessary on high-voltage work, and if there is a long cold season the question comes up whether it is safe to have them remain frozen.

Often in high-tension work the transformers indoors are protected from fire by fire-proof cells. If put outdoors without cells, unless they are much more widely separated, the transformers presumably lose most of the advantage of that isolation; or if cells are used the expense will approximate that incurred in the indoor construction. The matter of lighting an open space is a small item which is sometimes lost sight of in outdoor installations.

In the examples Mr. Randall pointed out, the saving by outdoor stations is entirely incommensurate with the amount of risk and difficulty incurred, but I judge that this would not be true in all cases. In the first case the interest at 10 per cent on the excess cost of the housed plant would be $365 a year, which might be exceeded several times by the cost entailed through the increased difficulty in handling one or two cases of trouble. In the other case, with a little larger plant, 10 per cent interest on the increased cost of the housed plant would be about $1,300.

In the terminal described by Mr. Reynders we have an ingenious use of theory to increase the effectiveness of the terminal material. I think there is no doubt about the correctness of the theory, as is shown pretty clearly by the tests we have seen; but there are some difficulties to be borne in mind. Broadly speaking, the thing which is accomplished by this terminal is the favorable determination of the fall of potential along the surface of the bushing. Puncture through the material is relatively easily cared for; but to prevent a concentration of potential locally on the surface of the terminal, when the conductor has a very small diameter, it is necessary to take some precaution. As has been clearly explained, by making use of the fall of potential within the solid material and balancing the area of the small condensers, equal steps on the surface of the terminal are obtained. As the result of this follows a condition which, while theoretically dangerous, very probably will never arise; that is, if the terminal is designed for ordinary commercial frequencies, the larger current of the small condensers formed by the tin-foil, over and above the true surface leakage current, is the important factor in determining the distribution of potential. If, however, the leakage current over the surface or through the terminal itself should be larger than the charging current of the tin-foil condensers, then the fall of potential over the surface would determine the potential between these tin-foil layers, and the potential drop would be relatively much higher on the first few sections.

As far as the surface leakage is able, it will disturb the condition of equal distribution of potential, putting a very high strain on the inner layers. This condition is, fortunately, not likely to be serious. If, however, we should make a direct-current high-potential test, the charging current to these internal condensers would become practically zero, and the potentials would be determined by the leakage current over the surface, in which case the distribution potential would be much disturbed. Fortunately, in the frequencies higher than normal which we are much more likely to have, the effect is the other way and only increases the safety of the terminal itself.

Mr. Moody called attention to the lining up of the weak spots. This is a matter which should have careful consideration. I believe, however, that the uniformity of material is satisfactory in apparatus of this sort, and unless actual trial shows up a weakness in this direction, there is not much to be feared. There is another danger, however, in that if a leak, even a small leak, does occur between two layers of tin-foil, the current passing through the leak will be very much increased by the presence of the conducting plates, because the full charging current of all the plate will pass through the weak point; whereas if the conducting material were absent only a very small current would pass through any given weak local path not passing through the insulation from terminal to terminal.

I am inclined to believe it the part of wisdom not to attempt to pass the high-tension terminals through a transformer top with an opening of small diameter. It would be better to provide a 20-in. opening than to have a terminal passing through an 8-in. opening in the metal cover. The strains and tendency to corona discharge are certainly greatly increased by the close proximity of the ground to the high-tension parts. It would seem that much effort should be made to have the mechanical construction of a larger insulating diaphragm more suitable for supporting the terminal rather than to attempt to find some way of carrying the high potential through a small opening.

If there were time it would be interesting to discuss a number of alternative forms of high-potential terminal. I do not believe the last word has been said on the subject yet, and in closing I call attention to the condition shown in Mr. Reynders' paper— of a very small diameter of conductor in proportion to the outside diameter of the insulation. That ratio emphasizes the tendency to concentration of potential drop in one portion of the insulation. It is perhaps a favorable condition for the shaping of the tin-foil condensers of this particular type of terminal—the condenser terminal—but some other form of terminal having a larger diameter of conductor would, in that very fact, have an advantage, so to speak, over the condenser form, by relieving automatically in quite large measure the tendency to local concentration.

D. B. Rushmore: The reason for the demand for outdoor sub-stations is the desire to keep the original cost low. That, to my mind, is the only advantage that outdoor sub-stations have, so that instead of asking the question "Where can we use these?" it should be "Where must we use them?" for unless financial considerations make it necessary, there seems to be no reason for their use. There certainly is not apparent any engineering advantage in using them.

In certain climates, however, where either of the extremes of heat or cold predominate, it is a question whether or not to put them outdoors. For instance, in the great heat of Arizona there would be a decided question concerning the desirability of installing large transformers outdoors. There not only the temperature rise, but the final temperature reached, is going to determine the life of the insulation. In that climate, lightning-arresters or any other installation must be protected in all possible ways from the heat, not that absorbed by conduction and measured by temperature rise, but the great heat that comes from the direct radiation of the sun.

In the extreme climates in the north the cold to a certain extent will prevent the operation of mechanical devices through the thickening of the oil. As long as everything runs without interruption a great many conditions are possible which are not advisable in emergencies. It is for the emergency condition that a large part of the apparatus and installations have to be designed. Under severe climatic conditions, great difficulty would be met with in taking care of a large installation where most of it is exposed.

The freezing of the electrolyte of lightning-arresters has been a serious problem, and the development of an electrolyte which will not be affected by freezing is the result of several years of experience. An electrolyte has been found which is not affected by freezing, but there is no indication that it is at all helped by that condition. It is, however, undesirable to have the apparatus more exposed than is necessary; for any transmission line now in operation there are a sufficient number of disturbances to make us consider seriously the question of any further exposure of the apparatus. In most of the long high-tension transmissions, and where on a 100,000-volt transmission line a few horse power is taken off, we will be confronted with a serious condition regarding the cost of installation. It is here that perhaps we shall be most strongly forced to consider the outdoor sub-station.

As I watched the experiments to-night, I was reminded of an installation which was worked under good conditions for a few weeks, and was then followed by a breakdown of the insulators. This is simply an example which goes to show that the breakdown of insulation is not an instantaneous one. Wherever we have a brush discharge, there we have the formation of ozone and, under certain conditions, of nitric acid. This is apt to bring about a slow deposit over the insulating material, and in that way, at the end of a certain time, to cause a breakdown of the insulation. While this is an interesting device, which has been considered in other forms before, in the particular cases that I have in mind it does not seem desirable for mechanical reasons.

Paul M. Lincoln: I believe I am not exaggerating in saying that the lead described by Mr Reynders marks the greatest advance in the high-tension art that has been made during recent years. One of the advantages of this lead and one of the most striking exhibits is shown in comparing Figs. 10 and 11—the transformer bushings are made for the same operating voltage. The smaller one—of the condenser type—has a test voltage of 2.5 times normal, while the larger one has a test voltage which is only twice normal, and will hardly withstand that.

When this device was first suggested, the lining up of the weak points of the insulation was thought to be a fatal defect; it was not until after the thing had been tried out thoroughly that this defect was found not to be fatal.

The method of construction is important. The terminals and bushings are made of paper wound up into form under a heavy pressure and a high temperature. The different layers are put together with a bond of shellac which goes into the joint of the rolling paper. The temperature is high enough to melt the shellac as it goes in, insuring a perfect bond between the adjacent layers. By that means a construction is obtained in which weak points are practically eliminated. When finished the tube is virtually a solid mass.

I would take exception to Mr. Moody's intimation that the lead lacks robustness of structure. I think there can be no bushing made which is more robust in its construction than the one shown.

There was one point that was brought out in the rain test which strikingly confirms one of the points brought out by Mr. Reynders. He has indicated that in designing the terminal it was necessary to sacrifice a perfectly even distribution of potential along the terminal, and that the potential was somewhat higher in the middle than at the ends. It was noticeable that when the terminal was flashing over it was mostly the middle condensers which were discharging, with very little discharge at the ends. This fact illustrates one of the points of construction which Mr. Reynders mentioned.

The spark gap, which is a shunt to the terminal, has been seen under test. The gap is set at 27 in., so that the voltage which was applied to the terminal was fully 250,000 at the time of breakdown, as the spark gap was in continual discharge.

E. M. Hewlett: I have been interesting myself for some time in the development of Mr. Frank's oil- or asphaltum-filled insulator which is now being used with high-voltage transformers. I hardly see the necessity of a complicated design when the same result can be accomplished in a simple way.

The bushing of this insulator consists of a built-up shell of insulating material which is filled with a high-grade insulating liquid or compound, such as oil or asphaltum, with concentric cylinders placed inside of the bushing to distribute the potential. This arrangement results in an insulator having the same arc-over value as the equivalent spark gap.

Considering storms, accumulation of moisture, general climatic conditions, and the trouble of making repairs, it seems as though the outdoor installation could never be a serious competitor of the protected station. In cold climates it would be necessary to use a special oil for the swithches or to heat the oil in order to keep it of the proper viscosity for the satisfactory operation of the oil switches.

S. Piek: Doubt has been expressed as to the reliability of outdoor terminals for high-potential transformers. The Niagara, Lockport & Ontario Power Company has had in permanent operation since October, 1908, six outdoor 60,000-volt series transformers, which have operated most successfully during the severe rain, snow, and sleet conditions of the last winter. On the strength of this performance there is no hesitancy to adopt this type of terminal for outdoor power transformers.

The saving in investment made possible by the use of outdoor transformers would be considerably more than the comparative figure in Mr. Randall's estimate, had the indoor station been provided with the facilities which are considered as arguments in favor of the outdoor installation. For instance, a steel building costing $3100 for housing transformers of 2000-kw capacity would hardly have enough floor room and head room to lift a core out of the transformer bank. A building designed to afford such facilities will cost considerably more, possibly double the figure used in the estimate. Furthermore, no allowance has been made for heating facilities which are essential to permit of repair work in any season of the year.

The outdoor transformer arrangement follows closely the traditional indoor station layout. If the money now spent for choke-coils and lightning-arresters were partly applied to the improvement of the transformer installation, the result might be an almost indestructible transformer, which could be placed at any point on the line without requiring much attention for its maintenance.

The Niagara, Lockport & Ontario Power Company has felt the need of outdoor transformers for a long time, and could probably increase its load immediately by 3000 or 4000 kw. if outdoor 60,000-volt transformers were to be obtained.

Guido Semenza (by letter): It is natural that reaction from any exaggerated condition should itself be exaggerated. The indoor high-tension sub-station has in some instances reached such a high degree of complication with walls, partitions, cells, and conduits that the general feeling is that things have been pushed beyond the necessary limit. Then we are brought by the reaction to the opposite extreme—no walls and no roof. This new form of sub-station requires very careful investigation, and Mr. Randall is to be thanked for having brought the matter before the Institute in such a clear and impartial manner.

In comparing Fig. 3 with Fig. 4 in Mr. Randall's paper, we are impressed by the simplicity of the outdoor arrangement; but if we consider it well we find that some of the objections pointed out by the author and others cannot be neglected. First of all I quite agree with Mr. Randall that if a part of the station requires housing, the extra cost for housing the whole will not be of great importance. Measuring instruments and controlling panels will not be improved by rain and summer sun. Nowadays a marked tendency is shown toward being able to read instruments in every part of the plant, so that in many cases the outdoor arrangement would not be feasible.

As Mr. Randall states, outdoor apparatus should not only be water-tight, but also air-tight. I am very doubtful if a perfect condition of air-tightness is possible at the inlets, where substances of a very different coefficient of expansion are used, such as porcelain, mica, iron, copper, and compounds. Apparatus repaired under conditions of rain, mist, or snow are liable to deteriorate, and we do not always find customers inclined to wait for a sunny day before having their current put on again. Outdoor sub-stations are not easily protected from direct lightning strokes.

With reference to insulation, I venture to point out the fact, often observed, that in moist air, when porcelain and iron are in contact, the iron rust gradually penetrates the glazing of the insulator, causing a breakdown after a time.

Mr. Randall figures out the cost of first installation only. This is not sufficient. If we take into account the cost of operation, I fear that the larger liability of breakdown of open-air insulators and terminals, the necessity of frequent repainting, of cleaning off dust and insects, and the more accurate inspection required, will more than offset the lower cost of first installation. Thus I feel inclined to conclude that a fair solution would be to simplify sub-stations by making them more similar to the arrangement shown in Fig. 4, but to cover them with a roof, and wall them in.

Exaggeration in partition walls and cells was justified in the early years of high-tension work when switches were considered a dangerous device; nowadays we have more confidence in them and can do away with excessive protection.

A. E. Kennelly (by letter): The introduction of metallic layers into the substance of a dielectric for improving the distribution of electric stress, has been known and used to some extent in the construction of high-tension induction apparatus. It promises to be of considerable assistance in the construction of high-tension terminals in the manner described in Mr. Reynders' paper. This construction not only establishes equipotential surfaces within the dielectric, with a geometrical distribution which is under the control of the designer, but it also limits the range of influence of an accidental flaw in the dielectric to the distance between adjacent conducting layers in the vicinity. This capability of injecting artificial equipotential surfaces is a fortunate property of alternating-current tensions not possessed by steady, or direct-current tensions.

If a condenser type of high-tension terminal were used on direct-current pressure, and any slight leakage to ground occurred from the layer of tin-foil nearest the central conductor, it would only be a question of time for that layer to sink to ground potential through the leak, and thus bring the entire difference of potential stress on the innermost wall of the dielectric; whereas, with alternating current no such cumulative action can occur, and the influence of external leakage current in adding to internal stresses is only in the proportion of the leakage in current to the total condenser current through the dielectric mass.

One of the problems of aerial transmission insulator design may be regarded as analogous to the problem presented in the design of a condenser type of terminal. That is, the glazed surfaces of the insulator should be disposed in such a manner that when they are temporarily converted by rain water into equipotential surfaces, the stresses on the intervening dielectric layers in the insulator shall not be materially altered, and, in particular, shall not be locally increased to a dangerous intensity.

It is doubtful whether the introduction of concentric cylindrical tin-foil layers into the uniform dielectric of a cable can be of utility beyond limiting the radial influence of flaws in the dielectric; because the equipotential surfaces in such a cable are already concentric cylinders, so that in the absence of flaws the introduction of thin tin-foil changes nothing. When, however, as in transformer terminals, the construction is in three dimensions and the equipotential surfaces are no longer simple concentric cylinders, the insertion of the tin-foil alters and controls the potential distribution.

J. S. Peck (by letter): In reading Mr. Randall's paper, two questions suggest themselves to an engineer somewhat familiar with the conditions governing the use of high-voltage apparatus in Great Britain: 1. Will the Board of Trade and the Home Office approve of an outdoor installation? 2. If they do approve, will not their approval be qualified by the imposition of such measures for the protection of the public and operatives, as would make the cost of the outdoor installation as high or higher than the indoor one? Assuming, however, that such severe restrictions are not imposed, and that, as in America, each engineer has practically a free hand to lay out his system as he sees fit, the question appears to resolve itself into a discussion of the conditions under which an outdoor station may be desirable.

The only real argument in favor of the outdoor high-tension station is its low cost. The argument of reduced fire-risk is of secondary importance, while regarding risk to life there is considerable doubt if the outdoor station is as safe as the indoor one, though there is something to be said on both sides. So far as cost is concerned, it would appear certainly that the outdoor has a considerable advantage over the indoor station, but when one notes the way in which the appearance of the handsome building of the Lockport station of the Niagara, Lockport & Ontario Power Company referred to by the author, is disfigured by the forest of poles outside it, the possibility of a compromise is suggested. It may be found that in the long run it will pay to protect transformers, switches, and arresters from the direct action of rain, wind, and snow, by some cheap form of building or shed which will be no more offensive to the aesthetic taste than an outdoor station consisting of a mass of poles, insulators, wires, metal tanks, earthenware jars, and fences for keeping off the sun.

The strongest argument against the outdoor station is the possibility of damage to the apparatus through the absorption of moisture. This applies particularly to the transformers, which, being alternately heated and cooled, tend to breathe out hot air and breathe in cool air, the latter possibly being saturated with moisture. As the author suggests, while it is possible to make the case vacuum tight, this is a difficult and expensive matter; and even if vacuum tight when installed, it is an open question whether the case will remain so. Apparently the transformer case shown in Fig. 11 is not vacuum tight, and it would be interesting to know whether the costs of the outdoor stations given would be increased appreciably by making the transformer cases vacuum tight.

In Europe it is almost common practice to protect all transformers from the weather, even those of small capacity and low voltage. The very low mortality rate of transformers in Europe as compared with those in America, even though built to the same specification, leads to the belief that protection from the weather is an item of considerable importance, which certainly will not grow less as the voltage is increased.

Another danger with the outdoor station where water-cooled transformers are used, is the freezing of the water in the cooling coils in the event of a transformer being cut out of circuit for several hours. It is extremely difficult to remove all water from the coils, and a frozen coil usually means a burst one. When the transformers are placed inside a station, it is usually possible to keep the temperature of the station above freezing point.

Mr. Randall apparently assumes that 500 kw. is about the limiting size for self-cooling transformers, but in Great Britain there are a number of 1000-kw, 20,000-volt, 40-cycle three-phase transformers in operation. There is no reason why 1500 to 2000-kw., 50-cycle units of the self-cooling type should not be made, even without auxiliary cooling tanks.

On account of the relatively heavy expense of terminals for very high voltages, and of the difficulty in making them weatherproof, the advantage of using only one terminal on each transformer becomes more apparent whenever the star connection is used with grounded neutral. It should be noted also that with this system the series transformers may be grouped about the neutral point, so that practically no insulation is required for the terminals or between the high tension and ground. Where it is desired to measure the total output of two or more groups of transformers, the secondaries of the series transformers on the different groups may be parallelled.

As stated previously, it is doubtful whether the outdoor station is ever likely to come into favor in Great Britain on account of the possible objections of the Board of Trade and the Home Office and of the aesthetic feelings of the people, but in America, where the use of outdoor transformers of small size is already universal, the outdoor station seems bound to follow. The only question, then, is to determine the limits of size, voltage, etc., beyond which it is better to house the apparatus that may be damaged by the weather and which it may be desirable to inspect or to cut in and out of service from time to time. What these limits are must be determined by experience.

Ralph D. Mershon: Both the papers presented this evening represent a distinct advance in the art of high-voltage transmission. Mr. Randall's paper especially deals with a subject in which I have been interested for a long while. I believe that eventually outdoor high-voltage apparatus will be the rule rather than the exception. I can well remember the indulgent smile with which I was met on making suggestions along these lines several years ago. Even Mr. Randall himself, who is most ready to consider any suggestion which may appear to contain elements of progress, seemed to have grave doubts as to the possibility of successful outdoor high-voltage apparatus.

There are two suggestions made by Mr. Randall which especially interest me. One of these is that of considering the high-voltage apparatus a part of the transmission line, and switching the apparatus and line as a unit. I think in time this course of procedure will prove desirable in many cases where large amounts of power are to be handled, and the transmission is over long distances. The other suggestion is that of putting all the high-voltage apparatus in one tank, so as to require the minimum number of terminals. This is a matter to which I hope the designers of high-voltage apparatus will give careful attention.

It would be interesting to know from Mr. Randall the minimum temperature at which the oil switch could be operated, in view of the fact that the oil will thicken as the temperature is lowered. It would also be interesting to know as to the possibility of putting the complete oil switch, including the mechanism, inside the transformer tank and, possibly, underneath the oil.

I agree with Mr. Piek that Mr. Randall has not allowed enough for the cost of his buildings. In designing a transformer station it is surprising how the cost runs up, and the various details that have to be taken care of are numerous. The point Mr. Piek made is a very good one; that is, if we have room to handle the transformer in the station we will require more room than Mr. Randall provided.

Mr. Peck raises a point which has always interested me; that is, the fact that in using single-phase transformers with the high-voltage side connected in Y, we need only one high-voltage terminal for each transformer, and that by such a method of connection we may locate our series transformers near the neutral point, thus avoiding the necessity of insulating them for high voltages. If such course be pursued, it seems to me that it might possibly pay to go further and bring a lead out from the high-voltage winding near the neutral connection, from which could be actuated the voltage-measuring instruments and the reverse relays where such are required.

Mr. Peck's suggestion brings to mind another point which has always interested me, and that is the desirability of being able to connect both sides of the transforming apparatus in Y, resulting in the same simplicity on the low-voltage side as that obtained on the high-voltage side. As is well known, we hesitate to follow this course now because of the difficulty met with when the neutrals of generating apparatus are connected. This difficulty is generally assumed to be due to the effects of the third harmonic. It is very desirable that this question be given closer investigation, experimental and theoretical, than it has heretofore received, with a view to overcoming the difficulty if possible.

If separate single-phase transformers are used in three-phase transformation, with both high-voltage and low-voltage windings connected in Y, each transformer and the line cable connected to it may be treated as a single-phase unit; that is, the three-phase transmission circuit may be considered as made up of three single-phase circuits 120 degrees apart, and handled accordingly, so that where the return current through the ground would not be especially objectionable, we might, in cases of emergency, switch out a part or all of the transforming apparatus connected to one line conductor and run for a while on the other two phases. Such a possibility as this would greatly increase the flexibility of a transmission system. In this case our switching apparatus would preferably consist of single-phase switches arranged so that they might be operated as such, or, when desirable, operated simultaneously, thus constituting a three-phase switch. Under such conditions the suggestion made by Mr. Randall, of putting the switch in the same tank with the transformer, becomes very attractive.

Of the many written contributions received, one of them, for the reading of which there is not sufficient time, deals with the idea of locating the high-voltage bus-bars and some of the remainder of the high-voltage apparatus on the roof of such small building as may be required for sheltering the sub-station operator and the switchboard measuring and control apparatus. This is a suggestion which has been made a number of times, but, so far as I know, has never been fully worked out. It opens up a subject worthy of further study, as possibly leading to desirable results in economy, reliability, and safety.

Mr. Reynders' paper is a beautiful exemplification of the application of theory to practice, and the advance which it marks should do much in forwarding high-voltage transmission work through the cheapening of reliable apparatus.*

W. S. Franklin: It has occurred to me that I might briefly consider the accumulation of charge upon a high-voltage transmission line, an accumulation which continuously discharges to ground and which is called the "static discharge" by transmission engineers. The maximum voltage that can be created between a pair of single-phase transmission lines and the ground is equal to $\frac{2\sqrt{2}\,C\,E}{C'}$ where E is the effective alternating voltage between the transmission lines, C is the capacity per unit length of the pair of transmission wires with respect to each other, and C' is the capacity of the pair of transmission wires with respect to earth. Thus, a maximum pressure of 560,000 volts may be built up between a pair of transmission wires and earth when the voltage between wires is 40,000 volts effective, and when C is five times as great as C.'

The theory of this effect, as I have worked it out, is based upon the great mobility of the negative ions in the atmosphere as compared with the positive ions, and indeed the above formula is based upon the assumption that the mobility of the positive ions is negligible in comparison with the mobility of the negative ions.

The building up of an excessively high voltage between a pair of line wires and earth does not depend upon a potential gradient in the atmosphere but, so far as the above formula is concerned, depends solely upon the existence of free ions.

N. J. Neall: There is one curious arrangement shown for the outdoor stations that indicates the persistence of established practice, and that is the lightning-arrester equipment which is placed at one particular end of this group of apparatus. I see no reason whatever why it should be used on only one side of the group, so to say. In fact, let us suppose that these sets represent future practice with very high voltages where the transmission lines will be provided with overhead grounded wires. I observe that we have here no overhead grounded wires for the station. I think it only fitting, however, that we should supply the equipment with a static shield also, but the preparation of that static shield will not be so simple when all the wiring now shown is taken into account. A modification of this—but to some extent begging the question—would be to scatter lightning-arresters throughout the group, just as many as the station would afford.

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* Before the close of the meeting, Mr. Mershon said that the thanks of the Institute were due to the Electrical Testing Laboratories for the loan of the testing apparatus used for experimental purposes at the meeting, and to the New York Edison Company for installing it.

G. Faccioli: The so-called condenser type of transformer terminal has attracted the attention of manufacturers and engineers for years. In May, 1906, the *Elektrische Bahnen und Betriebe* gave a full description of such leads and the complete theory thereof. In that paper, as in the present paper, the terminal is compared to a short piece of cable; but a transformer terminal is under very different conditions from a short cable, and the distribution of the stresses is not the same in both cases. In a transformer lead the inside conductor is much longer than the outside grounded plate, and, therefore, all formulas which apply to cylindrical condensers where the inside and the outside plates are of the same length, do not apply to the case of leads.

A simple experiment shows this clearly. Let us take a rod 45 in. long and 0.25 in. in diameter, and let us put this rod in the center of a metallic cylinder 10 in. in diameter and 2 in. long. We ground the outside cylinder and apply to the rod high potential from the terminal of a transformer whose other terminal is grounded. We find that as soon as we reach 40,000 volts, part of the rod covered by the grounded cylinder glows. This means that at the surface of that portion of the rod the electric stress is higher than the disruptive strength of air.

If we raise the voltage, corona will gradually spread on each side of the center of the rod. If we increase the width of the grounded cylinder, we find that the first part of the rod to glow is always in the center and very short in length, showing that the distribution of the electric field is not uniform, but is the strongest in the center and decreases gradually on either side.

Now let us put a thin copper cylinder 5 in. in diameter and 10 in. long concentric with our rod and the grounded disk. If we test the apparatus, we find that corona appears in the center of the rod at 43,250 volts, which is very little above the 40,000 volts found before. This shows that the introduction of the intermediate concentric cylinder in the electrostatic field has changed its distribution very little. We can conclude from this test that the condenser type of lead must have comparatively small diameters and short steps between adjacent tin-foil layers. A small diameter necessitates an abnormal length of lead, for we know that in order to reduce corona and creepage effects, an increase in diameter is far more efficient than an increase in length.

For instance, the condenser lead illustrated in the paper has a length above ground of 49 in. Successful leads for the same voltage have been built with only 39 in. above ground. Their diameter is, however, 7.75 in. in the center. Such leads do not arc over at 250,000 volts, although their length is 10 in. less than the condenser lead.

The condenser type of lead, however, gives a better distribution of potential on the surface of the lead; in fact the equipotential surfaces are straightened by tin-foil cylinders and tend to relieve the crowding of the voltage near the grounded plate. On the other hand, the mechanical construction is very delicate: the lead has to be built cylindrical and then machined to smaller dimensions, and the metallic cylinders connect in series all air bubbles and other faults which are very apt to occur in this kind of construction.

Furthermore, Mr. Jona, in his article referred to in this paper, brings out the point that the introduction of metallic cylinders in the mass of the insulation decreases the resistance to puncture of the apparatus. He gives the example of a copper wire 4 mm. in diameter, insulated to 8 mm. in diameter, then covered with a thin metallic cylinder, next with 3 mm. more of rubber, and finally with a lead sheath. At 8000 volts the insulation between the small wire and the metallic cylinder is punctured; but if the metallic cylinder is removed the insulation is not punctured up to 15,000 volts. The phenomenon is not clearly understood.

We consider in our calculation the different layers of insulation as independent and subjected to a certain difference of potential from one surface to the other. This view, according to Jona, is probably too "static." The phenomenon of "puncturing" is dynamic, and consists in the flow of a certain amount of energy which cannot reach one layer of insulation without going through the other layers. It seems that the various layers of insulation give a considerable mutual assisting action, which is evidently lost if they are separated by metallic surfaces.

In conclusion, as far as puncturing is concerned, this new lead has no advantage over the bulk type of lead, but the fact that the distribution of potential on its surface is much more favorable makes this lead a very desirable apparatus.

C. L. de Muralt: One point which I should like to emphasize is that in the design of our transformer leads—which are the first part of the power-house equipment in connection with the line—we are working against a constantly decreasing margin of safety. It is comparatively easy to take care of the line working-pressure. Even the excess pressures produced by static charges and high-frequency discharges on the line can be handled. But the very apparatus which annihilates the effect of these outside excess pressures may, in connection with the transformers, produce resonance effects which bring on local excess pressures of magnitudes more and more dangerous the higher the line pressure goes

Transformer terminals and transformer windings have a certain capacity against ground and a certain self-induction. Lightning-arresters usually have a certain ohmic resistance and a spark-gap of some kind. These, with the ground, form a resonance circuit.

So long as $I R^2 > 4 L$, we are on the safe side and there will be no resonance. If $I R^2 < 4 L$, we will have excess pressures which may easily reach multiples of the working pressure. It is therefore necessary to make the ohmic resistance of the lightning-arrester very high. At the same time this resistance should be as low as possible to handle readily the very large currents produced by the outside excess pressures. We have here two absolutely opposing conditions.

I have worked considerably along this line and I offer a solution which I have found safe for very high pressures. Metallic rods connected to the ground are first insulated and then surrounded by a series of metallic discs. The lowest disc is connected to the ground; there is a gap between every two discs, and the last disc is connected to the line by means of a high resistance and a spark-gap. We thus have a series of spark-gaps and also of capacities. Several such devices are then placed in parallel. Each one has a resistance high enough to prevent resonance. The resistance of the group in multiple is low enough to allow any current —thousands of amperes—to pass to the ground without trouble.

Of course the spark-gaps will not operate all together, as they cannot be thus closely regulated. One starts, and as the excess pressure increases others are brought into service until relief is obtained. By these means we have been able to keep the excess pressures within 10 per cent of the working pressure, thus giving a very large margin of safety to transformer terminals even with very high line pressures.

V. D. Moody: As covered by the summary of Mr. Randall's paper, the problem from the manufacturer's view involves three distinct features; the transformer, the switching apparatus, and the protective apparatus. To these items there should be added another and most important factor which is involved; that is, the saving in cost of the plant in locating the apparatus outdoors instead of indoors. As concerns the high-tension bus-bars, there is no good reason why these should not be located outside in every case, as they are practically a termination of the transmission line.

The apparatus directly involved in an outdoor installation comprises lightning-arrester equipment, choke-coils, oil switches, and transformers. With the adoption of the aluminum-cell lightning-arrester, which is built to-day for outdoor installations, there remain three factors for the designer to deal with. At the present time there is in outdoor operation numerous transformers wound for 10,000 volts; and there should be no reason why outdoor operation would not be possible with higher voltage. As for the oil switches, these can be made water-proof as readily as transformers.

In transmissions of 10,000 volts, where self-cooled transformers can be applied with the downward projecting insulated lead which issues from an overhanging pocket near the top of the transformer case, an outdoor application is perfectly safe where the transformer is located on an elevated platform; but for higher voltages, where the oil-insulated, water-cooled type of transformer is necessary, with the leads projecting out of the top of the case, several factors are to be considered. Due to the weight, this transformer would necessarily have to be located on a foundation. In climates where severe snowstorms are encountered, the transformers and oil switches should be protected by some kind of shed, otherwise they are likely to become submerged, grounding the system. This shed is also a necessity in the summer months, to protect the oil-insulated apparatus from the intense heat of the sun's rays, as well as acting as a shield to the insulators of the apparatus from brick-throwers and sharpshooters. In addition to the shed covering the apparatus, the latter should also be surrounded by a wall or fence, in order to keep the inquisitive out of the danger zone.

In high-voltage transmissions the transformers should be protected on the high-tension side by disconnecting and automatic oil switches. On this point I cannot agree with the suggestion:

> * * * that by treating the high-tension side of the transformers as a part of the line, no high-tension oil switches would be required, but fused disconnecting switches placed on the high-tension side would serve to cut out the transformer.

This might apply on a 6600-volt line, but even in this case I would recommend oil switches. The fuse proposition on a 6600-volt line is a very expensive one, as good protective fuses are costly, especially due to the number of fuses likely to blow. At the present stage of the art, in speaking of high-tension apparatus, we have in mind voltages from 40,000 up; fuses for such voltages would be absolutely prohibitive as well as poor practice.

In describing an outside station, Mr. Randall says that as no instruments are employed, no attendants are necessary. I do not agree with this statement unless the station is located in close proximity to another station containing the low-tension apparatus, so that the switching can be readily looked after, or the switches are electrically operated from a distance. If a station were connected on the high-tension side by only fused disconnecting switches, any possible trouble that might occur—blowing a fuse—would cause an inconvenience that might not only be annoying but costly to the consumer.

If it is desirable to locate the high-tension apparatus outside, the ideal arrangement for a switching or transformer station where no secondary machinery—as motor-generators—is necessary, would be to locate the apparatus—including the lightning arresters, choke-coils, oil switches and transformers—under a shed, the station being surrounded by a fence in populated districts, the low-tension apparatus, consisting of switchboard, etc., being housed. The transformers should be protected by electrically operated oil switches, operated from the switchboard by the station attendant, and by disconnecting switches on the high-tension side. If the low-tension voltage for distribution is 2300 volts, hand-operated automatic oil switches, mounted on the back of the switchboard, and disconnecting switches should be used between the secondary of the transformers and the low-tension bus-bar. If the low-tension voltage is 440 volts or thereabouts a saving could be made in the switching apparatus on the secondary by using only disconnecting switches between the transformer and the bus-bar, the outgoing feeders being protected by triple-pole, carbon-break circuit-breakers with overload release.

In using water-cooled transformers, it is essential in such a lay-out that attention be given to the cooling-water piping to prevent bursting from freezing, which necessitates the flow of water continuously through the coils. It is also necessary that the attendant know at all times that this water is flowing. This can be taken care of by inserting a quick-flow indicator in the main water line, which should run through the station, and one on the incoming water piping at each transformer. This device shows the operator at a glance whether or not the water is flowing, and can be seen 25 ft. distant. To my knowledge it is the only safe device on the market for such an indication. It is now made electrically operated so that when the water stops flowing a lamp will be lighted.

I had the pleasure of assisting Mr. Randall in the estimates of costs of indoor and outdoor stations. In making these calculations it was apparent that in stations containing secondary machinery, as motor-generator sets, or synchronous converters, that the percentage of saving in placing the high-tension apparatus outdoors, instead of in compartments indoors, is very small, as there is involved only the cost of the building against the total cost of the installation plus the additional cost of weatherproofing the outside apparatus. It was evident that this percentage of saving decreases as the size of the station increases for a larger amount of secondary apparatus. In such cases the saving would not warrant locating the apparatus outdoors, due to the fact that with the transformers and switching apparatus in compartments they are absolutely protected from the weather, are more accessible for inspection or overhauling, and out of the way of molesters. The life hazard is less also. In simple transformer or switching stations, such as tapping from the transmission line to feed an outlying district for lighting and motor work, there is no doubt that the high-tension apparatus located outside, protected by a fence and shed covering, with the low-tension switchboard and switches housed, is a saving in cost well worth considering.

As regards locating oil switches outside of a station, under a lean-to, as suggested, I have at present in hand such a problem. The plant in question is now generating 36,000 kw. at 60,000 volts, delta. The output of the station is to be increased to 56,000 kw. by the addition of two vertical-type water-wheel-driven 10,000-kw. generators, and the transmission pressure raised to 85,000 volts, Y, with grounded neutral. The switches and bus-bars are now installed in masonry compartments, and it would be impossible, due to conditions existing, to use a 100,000-volt tubular switch which was desired, erected in the station, without tearing out the present bus-bar structure, involving a large expense.

The problem reverted to whether the insulating qualities and rupturing capacity of the present switches could not be increased to take care of the new conditions. The manufacturers found after a careful study of the situation that the pots of these switches could be made 6 in. deeper and 2 in. larger in diameter, increasing the oil space approximately 50 per cent and doubling the expansion chamber or air space above the oil, thus greatly increasing the insulating and rupturing capacity of the switches. From tests it was found that the insulation was satisfactory, but as there were no facilities in the factory for testing the rupturing capacity, this is not known; but there is no question that the switches are perfectly safe for the high-tension side of any bank of transformers, the maximum normal capacity of the largest bank being 18,000 kw. It is deemed advisable to install an outdoor 100,000-volt switch with a rupturing capacity of 200,000-kw. and this proposition is now before the engineers of the manufacturing companies. There is no doubt in my mind that the design of such a switch is not only possible, but will be called for frequently in the future.

These outdoor switches will be used only on the outgoing lines from the power house and incoming lines to the sub-stations, operating at 85,000 volts, Y, with grounded neutral. I am quite sure that these switches can be built, as the manufacturers are anxious to submit prices to take care of such a proposition.

M. W. Franklin: Fig. 1 in Mr. Reynders' paper shows the potential curve in the dielectric between the surface of the conductor and the grounded external circumference of the dielectric. The statement to the effect that it shows the distribution of stress is an error. Stress, which in this case corresponds with intensity of electrification, is the space-rate of change of potential and is therefore represented by the graph, not of the potential, but of the first derivative of the potential with respect to space.

The equations for the potential at any point between two coaxial cylinders must satisfy the condition.

$$\Delta^2 V = 0 \tag{1}$$

The equipotential surfaces are coaxial cylinders and therefore (1) may be written

$$\frac{d^2 V}{d r^2} + \frac{1}{r} \; \frac{d V}{d r} = 0 \tag{2}$$

which on integration gives:

$$V = c \log r + C_1 \tag{3}$$

when $r = R_1$, $V = V_1$ and when $r = R_2$, $V = V_2$, therefore

$$V = V_1 \frac{\log \frac{R_2}{r}}{\log \frac{R_2}{R_1}} + V_2 \frac{\log \frac{r}{R_1}}{\log \frac{R_2}{R_1}} \tag{4}$$

where V_1 R_1 and V_2 R_2 are respectively the potentials and radii of the inner and outer cylinders, and r is the distance of any point at potential V from the common axis.

The intensity of electrification at any point R at a distance r from the axis is

$$\mathfrak{Z} = -\frac{d V}{d r} = \frac{-(V_2 - V_1)}{r \log \frac{R_2}{R_1}} \tag{5}$$

This represents the force.

In the case of a homogenous, continuous dielectric, V_2 is at the outer circumference and is equal to zero. The equation (4) may then be written:

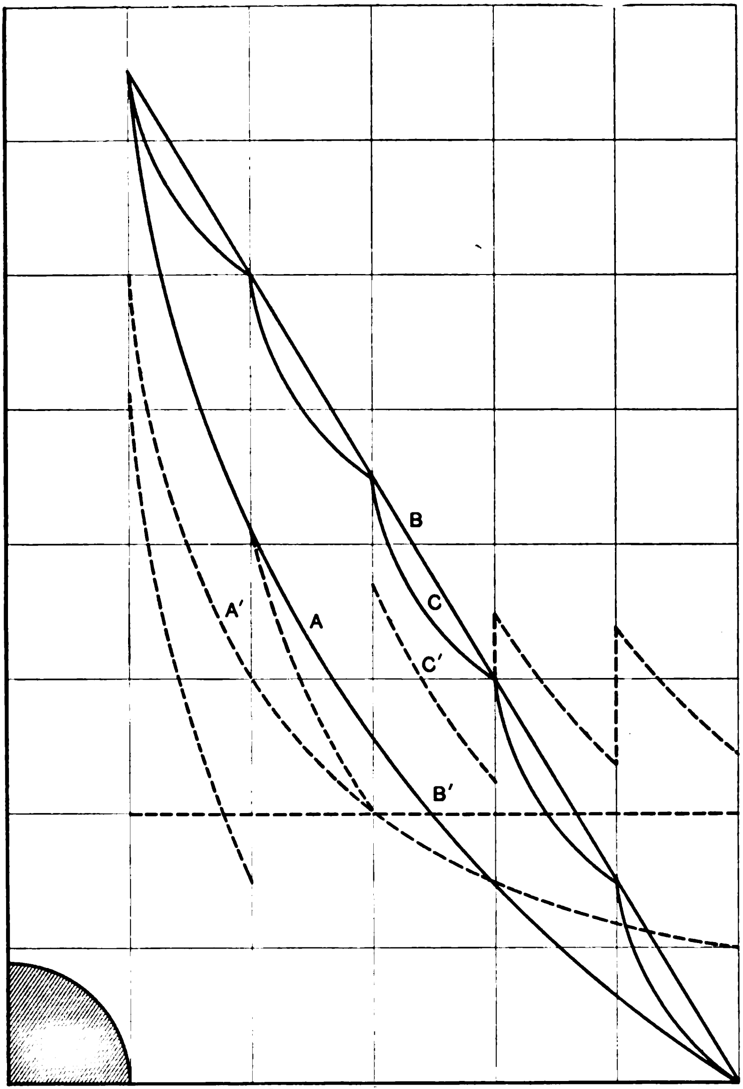
$$V = V_1 \frac{\log \frac{R_2}{r}}{\log \frac{R_2}{R_1}} = c \log \frac{C_1}{r} = k \log \frac{1}{r} \tag{6}$$

The graph of this function (curve A in the annexed illustration) is the potential gradient. Equation (5) reduces to:

$$\mathfrak{Z} = \frac{V_1}{\log \left(\frac{R_2}{R_1} \right) r} = \frac{C_2}{rg} \; \frac{1}{r} \tag{7}$$

and the graph of this function is the stress diagram and is shown in curve A'.

The condenser bushing here presented has for its object the attainment of a uniform potential gradient, as shown in curve B. The reason for this is that the derivative of such a function is a constant, as graphed at B', which shows that the force at any point in the dielectric is constant.



A, potential in a uniform dielectric; A′, stress diagram corresponding to A; B, ideal uniform potential curve; B′, stress diagram corresponding to B; C, potential for a series of concentric condensers; C′, stress diagram corresponding to C.

To this end, the dielectric is divided into a series of concentric cylinders, each forming the dielectric of a condenser whose plates consist of sheets of tin-foil interposed between them. The difference in potential between each plate and the next succeeding is a constant quantity, so that a line through the positions of the plates would indicate a potential curve as at *B*.

Were the number of plates infinite this would be strictly true throughout the dielectric, but in the case shown the stress gradient in the individual layers of dielectric must exert upon the results an influence which is not negligible.

The equation (4) for potential shows that though the potential differences between pairs of adjacent plates be uniform, the potential in the contained dielectric is not a straight line, but a logarithmic curve determined by equation (4). This is shown in the curves *C*.

The stresses in each section of the dielectric are shown in the curves *C′* which are the first derivatives of the curves *C*.

Referring to equation (4), it will be seen that the shapes of the logarithmic curves *C* differ as the position of the shell changes with respect to the distance from the center. The differences could not be shown in the small diagram.

Reference to equation (5) shows that the potential difference $f(v)$ being a constant for all shells, the constant $\log \frac{R_2}{R_1}$ varies with varying distance from center. The ratio $\frac{R_2}{R_1}$ becomes smaller while the value r becomes greater.

$\text{Log}\ \frac{R_2}{R_1}$ is a discontinuous function, and does not therefore lend itself readily to pure analysis, but correctly formed stress diagrams are plotted for each of several values of the function. These curves show that the stress diagram, far from being a straight line or even a smooth curve, is a series of discontinuous curves which introduce serious stresses in the dielectric. They also show that the stress distribution is very irregular, being greatest near the conductor, as with a uniform dielectric.

Geometrical considerations as mentioned in the paper necessitate the employment of various dielectric media to obtain equal capacities. This is unfortunate, as the different layers will expand and contract unequally, and mechanical strains of a serious nature will probably result.

The impossibility of avoiding sharp ridges and prominences on the surface of the foil will result in localized high potentials which will probably cause puncture.

Coaxial cylinders when charged are in a state of unstable equilibrium. When they are displaced even a small amount the capacity rapidly rises, the rise being proportional to the square and higher powers of the displacement of the centers. In the imperfectly rolled cylinders the irregularities correspond to equivalent displacements of center, and the stresses across certain limited areas of dielectric will be greatly increased.

K. C. Randall: The joints which were described as " vacuum tight" were so called as a measure of good joints. Mr. Moody's suggestion to maintain a weak pressure, so that there would be a slight outward pressure in order that any leakage would be outward instead of inward, is one that has frequently been looked upon with favor. It is true that the oil may freeze and become temporarily less effective through losing its insulating qualities, but the usual insulation margin in the quality of oil is sufficient to care for such a condition. Oil that will withstand 50,000 volts may drop down to 10,000 or 15,000 volts, and yet this very considerable depreciation in the insulating qualities of the oil may occur and the oil still be serviceable. The ordinary substations are not carefully heated. Furthermore, the heat due to the loss in most transformers will prevent the oil freezing solid. It is obvious that should the water in the cooling pipes freeze, the pipes would split and the next time water was turned on the transformer would probably be ruined. The obvious remedy is to adopt some means to keep the water from freezing, or arrange to drain the pipes.

Mr. Thomas pointed out the troubles of inspection and investigation, and particularly the daily routine of looking after the apparatus. That is more difficult, it is true, but the underlying fact is that nowadays our apparatus is getting better and better. A few years ago an occasional failure, or even a frequent failure, was not very much thought of. To-day a good deal of trouble is raised at a single suggestion of failure. How many moderately large transformers are taken apart and cleaned, or even looked over thoroughly? Once a year probably some of them are examined, but a goodly share are not. It would be difficult to repair an outdoor unit in a snowstorm, no doubt. The reference made to the heliostat seems to have been taken seriously by some one.

To summarize what I have said in the paper. Outdoor apparatus is not a panacea. There are places where it can be and will be used: there are some places where it is used to-day.

Mr. Mershon asked at what temperature cold oil would stop switches from operating. I cannot say positively, but I believe there is a non-freezing oil which at a temperature 35° fahr. below zero will still permit switches to operate.

In an outdoor installation the isolation of the units will be cheaper than for indoor stations, and consequently the security resulting from wide separation of units is more cheaply obtained.

Tight joints for transformer cases are equally desirable for indoor and outdoor units, so far as "breathing" is concerned, but the outdoor units require protection against rain, storm, dust, etc., not needed by indoor apparatus.

The standard 150-mil gap will give a test of from 6000 to 10,000 volts in oil taken from a tank with water under the oil. There are, doubtless, many transformers for 10,000 volts and over which are operating with water standing in the bottom of the case. It is also likely that an average test value of many oil samples taken from transformers in moderately high-tension service would not exceed 20,000 volts. The writer recalls a 60,000-volt unit which continues in perfect service, though the oil at one time tested only 15,000 volts.

These are some of the reasons for feeling that the limited depreciation of the oil dielectric due to freezing—which is quite improbable—will not endanger modern large outdoor transformers.

The field of the outdoor transformers is limited, but there are some notably economical installations. The Ontario Power Company is reported to have saved $2000 by an installation of 60,000-volt outdoor series transformers alone.

There are a few large outdoor 6600-volt transformer installations which are just as simple and satisfactory as the small house-to-house transformer installation.

Except in the very remote case of failure, it will not be necessary to inspect or work around outdoor apparatus, save in favorable weather chosen for the purpose.

A. B. Reynders: In Mr. Moody's remarks the lining up of the weak spots in the insulation was mentioned, and several subsequent speakers have brought out the same point. It is true that the weak spots tend to line up, especially if the insulation be thin. We have made terminals with three layers of 0.005 in. paper between tin-foil layers, and the terminal on test broke down at a relatively low value. The thickness now employed in the design practically eliminates this weakness. Mr. Moody also stated that the design employing oil, separated into layers by barriers of insulating materials, gave a very high dielectric strength. This is true, as the barriers of insulation act as an interference to the lining up of the particles of oil when under stress. This arrangement is not in any sense a condenser terminal.

The length of the condenser terminal above the top of the tank has been criticized as excessive. I wish to say that these terminals were purposely designed long. Observe the 66,000-volt terminal. This is used on an oil circuit-breaker. The operating mechanism is placed between the poles. As this mechanism extends some distance above the cover, and as it is necessary to obtain somewhat more than sparking distance between the top of this mechanism and the tip of the terminals, it required long terminals. Compare the terminal having a test of 180,000 volts with the terminal having a test of 250,000 volts. The latter is used on a transformer. It will be noted that the surface insulation distance in air is about the same as on the 66,000-volt circuit-breaker terminal. It will be further noted that the outside grounded band is extremely long. This is required by the design of the transformer tank and cover. It is necessary to have the lower end of the outside grounded band under oil and also to have the upper end of the same band on a level with or a little above the top of the cover. Owing to the "dome" required by the cover to withstand pressure, this long distance is necessary. Observe the short distance required under oil—in this terminal having 250,000-volts test, it is only 12.5 in., making 20,000 volts per inch.

Mr. Thomas spoke in favor of terminals of large diameter. This meets with no objection in the design of transformers, but for circuit-breakers it is practically impossible. For instance, a 100,000-volt circuit-breaker would require a terminal of the "bulk" type 20 in. in diameter, while the tank required would not permit the use of such large terminals.

Mr. Rushmore stated that brush discharge is detrimental, that it is doubtful if the condenser terminal will stand the test of time. We have made these terminals for 2 years and some of them are operating to-day at 200,000 volts to ground.

Mr. Neall thinks that manufacturing limits are reached in the terminals shown in this exhibit. I can state that we are now building a terminal for a test of 400,000 volts for 1 min., having approximately a diameter of 10 in. and a length of 117 in. We have a design under way for a terminal for a 500,000-volt transformer—one end grounded—having approximately a diameter between 15 in. and 20 in. and a length of 15 ft.

Mr. de Muralt stated that the factor of safety in terminals is too small for ordinary conditions of working. At the present time we are designing terminals for a test voltage which in commercial service is 2.5 times the normal operating voltage. The stress chosen for this test voltage is never more than one-half of the breakdown value of the insulating material, hence the terminals have at least a factor of safety of five.

Two of the speakers touched upon the theory of this terminal and attempted to show that either the addition of tin-foil did not improve the puncture value or else it was liable to produce harm in time. I will not take the time to answer these arguments, but wish to refer them to Jona's paper previously mentioned and particularly to a paper by Rudolph Nagel, published in the *Elektrische Bahnen U. Betriebe* for May 23, 1906.

Ralph W. Pope: I have here an insulator presented to the Institute by one of our charter members, E. P. Roberts of Cleveland. The inscription on the insulator is as follows:

> Insulator taken from old telegraph pole in Northern Wyoming about 1887 or 1888, by Wilbur C. Knight, mining engineer, and presented to E. P. Roberts, member of the A. I. E. E. The telegraph line was the first transcontinental and was built by Ezra Cornell, founder of Cornell University.

This type of insulator is peculiar. The early insulators were simply of glass; this insulator is of glass inside, and covered with a wooden shield. The object of the wooden shield is interesting. It was found that the glass insulators formed an excellent target for the marksmen of the plains, and the shattering of the glass was a never-ending source of amusement when the marksmen hit the insulator. Hence, this form of wooden shield was devised, so that the glass would not shatter. Consequently this type of insulator was generally used all through the plains. It was commonly known in the profession as the "nigger head" insulator.

F. G. Baum (by letter): In the early work of the transmission companies on the Pacific coast problems had to be solved within certain prescribed expenditures. What we were trying to obtain was a satisfactory delivery of power to small consumers without great expense or danger to persons or property. In some cases the transformers were set outdoors on ties and a shed built over them to keep out moisture, all switches, fuses, etc., being also outdoors. Many of the stations had no operators and often were visited only monthly, and the simpler the layout the better.

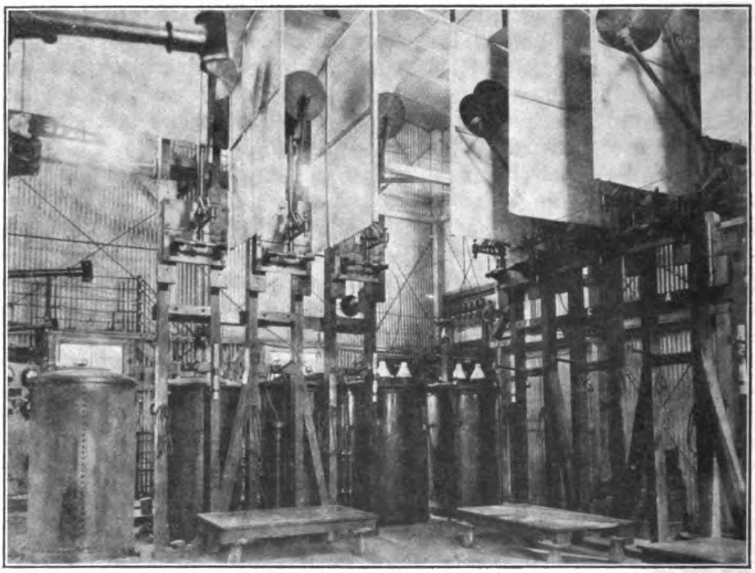


Fig. 1.—Interior of sub-station showing early type of switches

Fig. 1 shows one of the earliest interior sub-stations, with single-pole switches mounted on a wood frame, making the fire hazard very great. It was this sort of thing that kept the men on the alert day and night. Now nearly all the air-break switches and fuses are installed outdoors. Fig. 2 shows a modern type of switch. Fig. 3, 4, and 5 show some of the earlier types which may be interesting from a historical point of view.

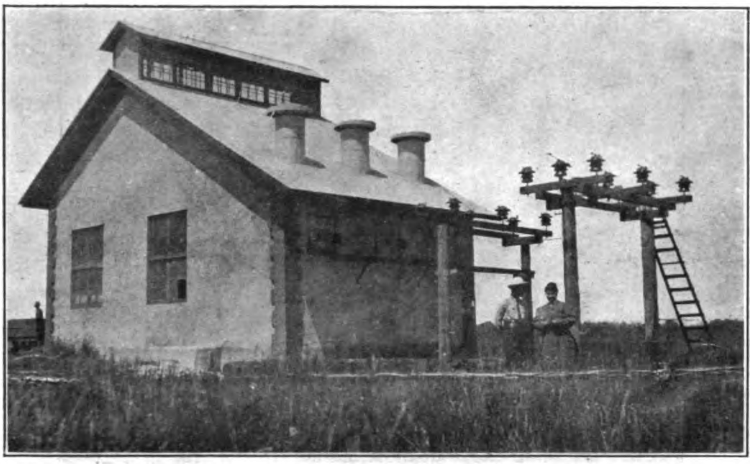


FIG. 2.—Modern outdoor switch with fuse

As voltages increase and power consumption becomes more general, there will arise a demand for transformer apparatus and switches to be mounted outdoors, thus at once reducing the investment, facilitating inspection, reducing fire risks, and decreasing operation costs.

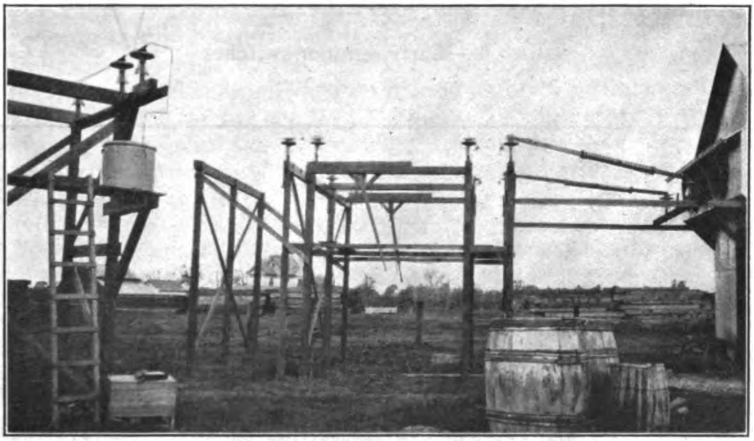


FIG. 3.—Early outdoor switches. Compare the choke-coil lightning-arresters with Fig. 10 of Mr. Randall's paper

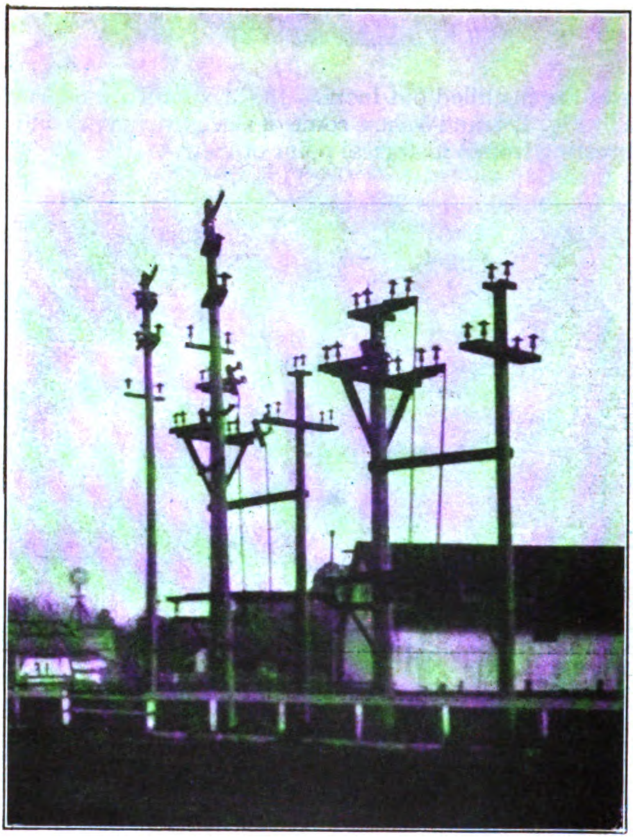


FIG. 4.—Early outdoor switches

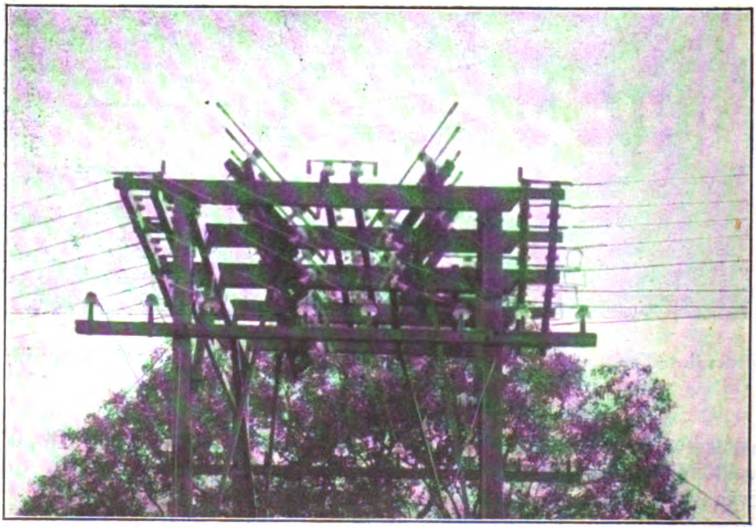


FIG. 5.—Early outdoor switches

O. S. Lyford, Jr. (by letter): Mr. Randall's paper relates to one of the most important steps recently taken in the field of high-tension transmission. The indoor sub-station, with apparatus operated at 40,000 volts or higher, is an absurdity. Not only is the cost of housing excessive, but because of the obvious necessity of economizing space as much as possible an excessive amount of engineering expense is incurred in developing the most compact safe arrangement.

The merit of the outdoor station will be most apparent where the amount of power to be transformed is small. Transmission companies are continually facing the problem of taking off blocks of power of 500-kw., or less at isolated points. At 40,000 volts, or higher, the cost of a sub-station, with the usual controlling and protecting devices suitably housed, is not very different for 100 or 1,000-kw.

The cost for the small sub-station, even of the outdoor type, will always be disproportionately high, but much can be done toward minimizing the cost by concentrating the transformer, circuit-breaker, and choke-coil in one tank. This plan was proposed at the Niagara Falls convention in 1907 and is referred to in Mr. Randall's paper. The merit in saving terminals is apparent from an inspection of Figs. 4 and 6.

Mr. Randall also refers to the recent development of a transformer construction which permits of shipment in the case with the necessary oil. If we can have a self-contained sub-station unit, ready for setting up in the field, and requiring with it only a small shelter for low-tension switching equipment and for repair purposes, the problem will be greatly simplified and the cost brought within reason.

Referring to the difficulty with moisture, the extent of breathing of a transformer is hard to realize without actual experience. The variation of oil level with change of temperature is much greater than would be represented by the respective coefficients of expansion of the oil, transformer core, and windings. This is apparently due to the porous and somewhat loosely built up insulation which absorbs and expels the oil as the temperature changes. This tendency to breathe can be provided for without admitting moist air to the interior of the transformer tank, if an adaptation of the U tube, with an oil seal, be used.

Referring to the terminals for outdoor transformers, the illustrations indicate that porcelain and composition types are both being experimented with. The writer has yet to see any composition material that has proved adequate for use in outdoor high-tension work. The vitreous quality and high glaze of porcelain seem to be essential.

Carl Schwartz (by letter): Two advantages are claimed in favor of the outdoor station: first, the cheapening of the installation due to a saving in building; and secondly, less life and property hazard.

Which type of installation, outdoor or indoor, is the most economical is not determined by low first cost alone. Any difference between the two schemes in cost of operation and maintenance should be capitalized and balanced against a difference in first cost. Also the value of safety of operation will have to be most carefully considered, even if this feature cannot be estimated in dollars and cents.

Reliability of service in generation and distribution of electric power has become of greater importance from year to year, and is recognized to be in almost all cases the most important feature. It will be admitted that delicate apparatus with complicated connections are apt to operate more reliably, can be better cared for and maintained for less money, if installed in suitably constructed buildings instead of outdoors. Inspection of oil switches placed outdoors is frequently difficult; dust, rain, and snow may cause serious disturbances at any time, if not during inspection.

Mr. Randall says:

> In order to obtain the cost comparison, the cost of the station grounds and indoor apparatus must be balanced, not only against the smaller building, but also against all the ground required for the outdoor apparatus, the outdoor apparatus itself, and the instruments and the indoor control apparatus.

In the estimate, however, the larger area occupied by the outdoor arrangement is not considered, and the saving in first cost shown in favor of the latter is to be reduced accordingly.

The two estimates for an indoor and semi-outdoor motor-generator sub-station show a saving of about $13,000 in favor of the outdoor scheme. This saving will be reduced to about $4,000 if the size of building is made more proportionate to the apparatus to be accomodated, and if the same class of building be assumed for both cases. Also, the same class of building will probably be erected whether some of the apparatus is installed indoors or outdoors, the general requirements being entirely similar. There is hardly reason for constructing a building of a cheaper class if only the smallest part of the apparatus be taken outdoors.

Hence it appears that the outdoor type of station may be somewhat more economical in case of a very simple transformer or switching station of high voltage with few or no instruments.

For a motor-generator station or a station requiring numerous instruments and attendance, the first cost of an outdoor station is not appreciably, if any, lower than an indoor station, greater economy in operation and maintenance and greater reliability always being in favor of the latter.

As far as less life hazard is concerned, the outdoor station is distinctly more dangerous unless it is protected against intruders in a most thorough manner. The property hazard, if this is meant to apply to the station building proper, even taking into account large quantities of oil stored in switches or transformers, is, as experience shows, extremely small if the station is sufficiently sectionalized and otherwise well designed, and is far overbalanced by the better protection afforded to the apparatus.

Concluding, I wish to say that we are fortunate in having available apparently well designed apparatus such as that described in the paper for use outdoors even under adverse climatic conditions. We know of circumstances where such type of apparatus can be used to advantage. I believe, however, that it would not be wise to promote the building of outdoor stations and to develop apparatus for them, to save in first cost by sacrificing reliability, while increasing costs of operation and maintenance. It would rather appear advisable to endeavor to limit the use of outdoor-type transformers, switches, etc., to cases where complicated connections and other undesirable features result, should such apparatus not be located close to the line and should it become necessary to bring high-potential wires with perhaps numerous crossings to and into buildings. This applies, for instance, to sectionalizing switches of high-voltage trolley line systems where the location of such switches away from the line would cause serious complication, though in this case the use of high-tension switches of the outdoor type is to be considered as one of the disadvantages of the system.

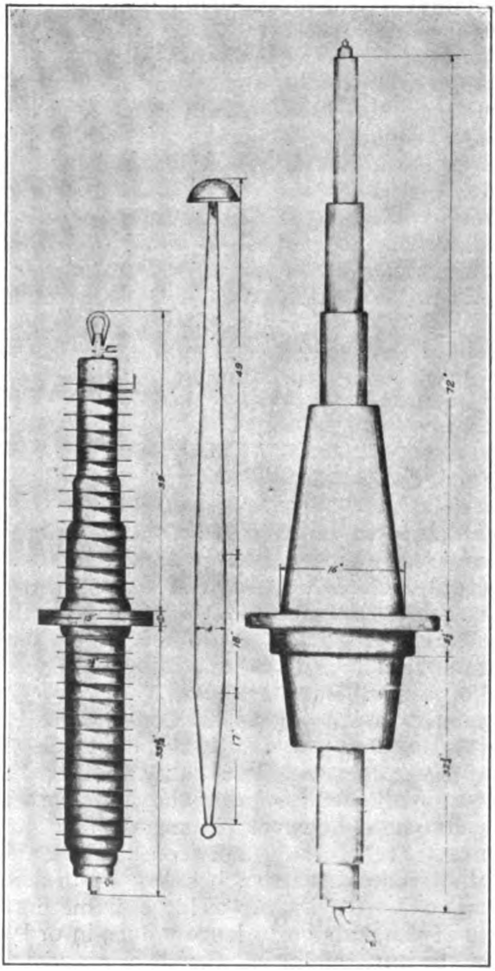
J. B. Whitehead (by letter): The most general expression for the capacity of two concentric cylinders is

$$C = \frac{k\,l + \Delta\,l}{2 \log \frac{r_2}{r_1}}$$

Δl is the correction term which depends on the length of the cylinders, their diameters, and the shape of the ends. The exact value of Δl leads to complicated expressions if it is attempted to express it for all cases. It is not probable that the requirements of terminals such as are here treated would necessitate taking account of this corrective value. The value of Δl for two cylinders 60 cm. in length and of radii 12.5 and 14.5 cm., respectively, with square ends, is between 2 and 3 per cent. Consequently, for the long narrow tubes as used in the terminals, even the difference of length of successive tubes would probably not introduce any error which could not be allowed for under the conditions of construction. It is well to note, however, the suggestion of this type of insulation for use in transformers between primary and secondary and primary and ground. In such cases the dimensions would frequently lead to short cylinders of large diameters. If the exposed surfaces of the ends go to large values in order to prevent creepage, it is not impossible that it will be necessary to take account of the end correction in the simple expression for the capacity concentric cylinders.

Referring to Mr. Randall's paper, a preventive for the trouble arising from the breathing of moist air in transformers might be found in the use of a double valve in which the ingoing air is carried through a drying agent and a free-one-way outlet is provided for expansion. In this way no pressure due to increased temperature would be applied to gaskets and other joints which it is aimed to make absolutely air-tight. It would be interesting to know also whether any investigation has been made as to the value of drying agents located in bulk within the transformer case.

John J. Frank (by letter): Supplementing the remarks by Mr. Moody relative to the oil-filled lead which we have developed, I would like to call attention to the illustration herewith showing a comparison of dimensions of such a lead with similar leads shown in Figs. 10 and 11. This lead has actually been tested and shows a failure by arc from terminal to ground of 250,000 volts. Attention is called to the reduced height of the lead as compared with the condenser type, Fig. 11, and the solid type as



shown in Fig. 10, which reduction in height was referred to by Mr. Moody as a desirable feature in the design of any lead.

W. L. Waters (by letter): The grading of insulation in high-voltage cables was first suggested by O'Gorman about 10 years ago, as a means of reducing the excessive amount of insulating material required in a high-tension cable with homogeneous dielectric. It was found, however, that the variation in the specific inductive capacity and dielectric strength of available insulating material was too small to obtain any very great commercial advantage from this arrangement. The condenser-type of terminal was next suggested about 4 years ago as a means of obtaining uniform stress on a homogeneous dielectric. As Mr. Reynders has pointed out, this type is limited by the necessity of obtaining sufficient leakage distance between the various metallic cylinders on the outer surface of the terminal. The terminal which Mr. Reynders has developed by combining the above two principles is the first really practical commercial type of high-tension terminal.

When the condenser type of insulation was first proposed, it was suggested that it might also prove advantageous for use in alternators and transformers. Its use for slot insulation on high-tension alternators was suggested as a means of avoiding the brush discharge from sharp corners on the laminations or conductors, and of avoiding the weakening effect of the air spaces usually present in a dielectric of considerable thickness built up in layers. Up to the present, however, it has been considered that in this case the difficulty of making a satisfactory mechanical construction more than counterbalances any possible advantage which might result. The advantages of this type of insulation for transformer work, as Mr. Reynders has pointed out, are very doubtful except in special cases.

It has long been recognized that the terminals were a weak point in a high-tension transformer, and that the solid type of terminal with uniform dielectric was of poor design on account of its high cost and great bulk, and on account of the difficulty of obtaining the dielectric perfectly homogeneous and free from defects. Mr. Reynders apparently decided that it was not worth while attempting to improve the solid type of terminal further, and took up the condenser type as being more promising.

L. L. Perry (by letter): Any engineer who has calculated the cost of a building to house switching apparatus for four or five high-tension circuits and a simple bus-bar, will appreciate the work done along the lines covered by Mr. Randall's paper. In planning several important transmissions, we have estimated on intermediate switching stations for the purpose of cross-connecting the good half of a defective circuit with the good half of a second defective circuit; and we have always concluded that it was not wise to spend the money until actual operation had demonstrated that the cost was warranted, especially since, at the beginning, the load is light and more spare circuits are available. It appears to me that for switching stations there is bound to be considerable development in the field treated of in this paper.

When we postponed the building of switching stations we hoped that the ground wire and the horn arrester would give more ample protection from lightning than the facts now show. Notwithstanding the great progress made in the last few years in arresters, it appears to-day that the greatest enemy to long-distance transmission is lightning. Our own experience has been confirmed by that of other engineers. A reasonable degree of protection has been obtained for the stations, but we still have before us the problem of the protection of the line insulators miles away from the stations. The overhead ground wire, the horn arrester, and the electrolytic arrester do not, so far as our experience goes, afford full protection. Since it seems improbable that full protection will be ever obtained, there are good reasons for putting in, on important transmissions, a certain number of switching stations, depending on the value of reliability. Such devices as have been used in the past have been crude, and there now seems to be a demand for more elaborate apparatus. Probably we shall soon use outdoor oil-switches on many of our lines of highest pressure, and their use on lines of lower pressure will increase.

Most transmission engineers have been confronted with the problem of tapping an important transmission for the supply of a few horse power; as a rule not only is there no money in it for the power company, but such tapping is a menace to the main transmission. If inexpensive devices are available it will be commercially possible to do things that the high cost of the older types of stations prohibited.

But it would seem to many of us that high-tension outdoor transformers could have but a very limited application, for where reliability of service is of much value it will be found cheaper to house the transformers. As electricity is more and more applied to electrochemical and electrometallurgical work, where often low power cost is of paramount importance, the minimum investment will rule and will tend to develop the outdoor station.

Nevertheless it would not be surprising if the application of such outdoor apparatus extended to transmissions for which its advocates do not now urge its use. We have had occasion to build some 6000-volt street-transformer vaults for feeding general light and power mains. Some of these have been built to stand flooding, and in them water-proof switches, transformers, and fuses have been employed. We have built others where there is no danger of flooding and the ordinary type of switch and fuse apparatus has been used. Contrary to our expectation the water-proof type seems preferable for many good reasons. It will require long experience to determine which is more reliable in service. The compactness, safety, and ease of repair of the water-proof type are great advantages. These vaults are not, of course, comparable to high-tension stations, for we used lead-covered cable for bus-bars and leads; but they have been cited to show that sometimes quite unexpected results may be obtained where such radical methods are adopted.

It is to be noted that the author does not go into the question of reliability. Most engineers would probably assert that an outdoor station such as that described by Mr. Randall could be of advantage only where a very low price is charged for power.

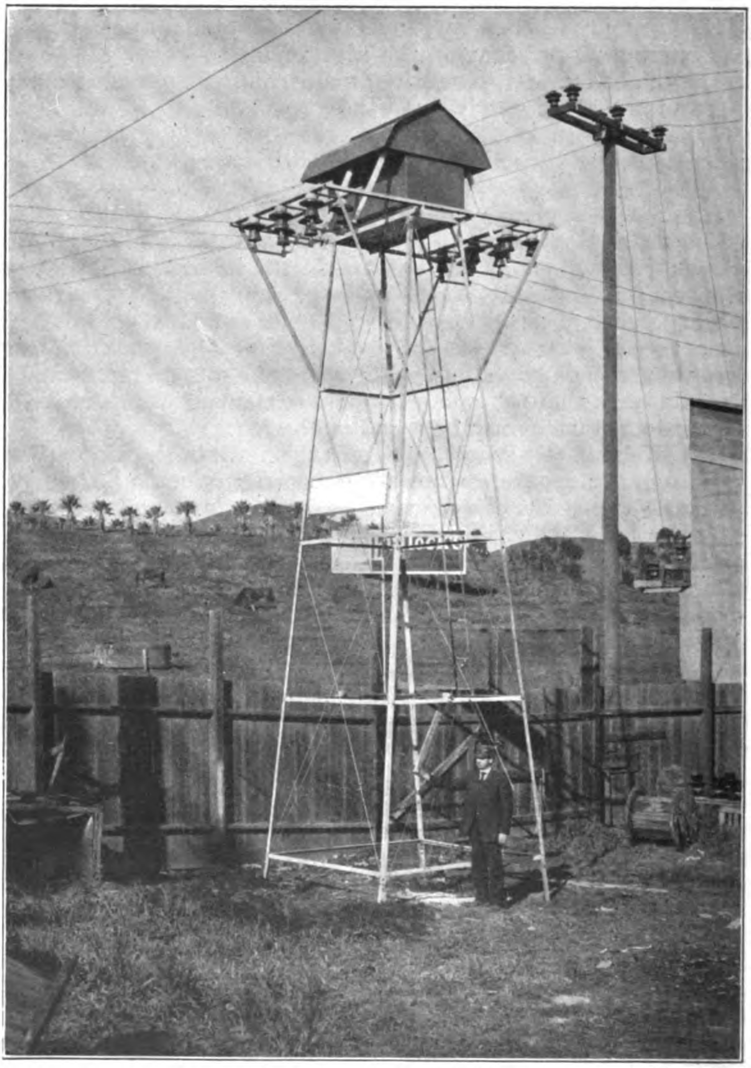
Assuming 20 per cent on the investment to cover all annual costs such as interest, operation, maintenance, repairs, depreciation and profit, the yearly cost will be:

Indoor station, 20 per cent of $15,100 or	$3020.
Outdoor station, 20 per cent of $11,445 or	2289.
Yearly saving	$ 731.

The yearly saving on the basis of 2000 kw. is only $0.37 per kilowatt capacity. If power be sold for as low as $16.00 per kilowatt-year, 37 cents seems no large sum to pay for extra reliability. But if power be sold for $32.00 or $64.00 per kilowatt-year, the 37 cents seem inconsiderable. These assumptions were that in each case 20 per cent covers all annual charges; but it would seem that the repairs, maintenance, and depreciation on the outdoor station must be relatively higher.

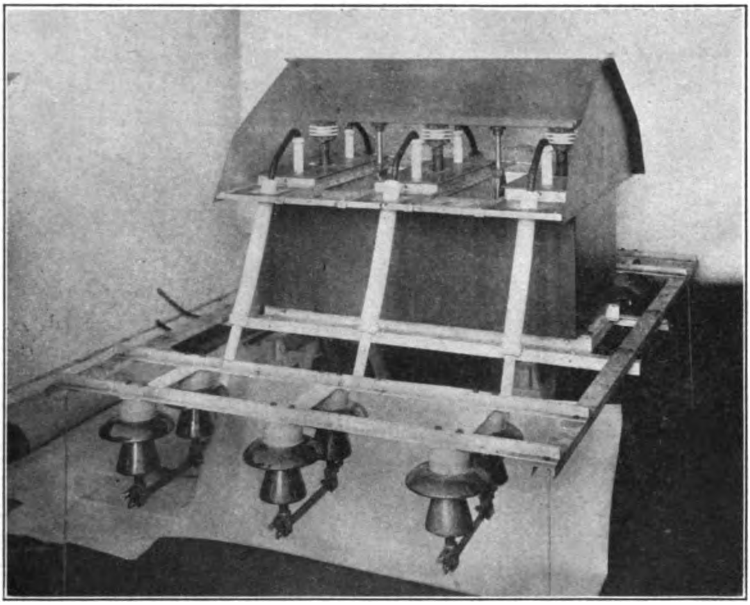
J. N. Kelman (by letter): The switch shown in the accompanying illustrations was designed for outdoor service on 30,000-volt systems. It consists of a weather-proof, three-pole, oil switch and two sets of disconnecting switches installed on a galvanized-steel tower. The oil switch proper consists of three separate iron tanks, each containing mechanism that gives a double horizontal break per pole, this break being so located as to leave two-thirds of the total volume of oil above it. Over each tank is placed a two-part insulating cover which serves to hold the leads in place. The leads are wrapped with varnished cambric for their entire length and brought out of the tanks and down to the disconnecting switches through heavy porcelain tubes, into which they are sealed with a special compound, then passing through the covers of the tanks and the plates in the eaves, both of these being of a high-voltage insulating material mechanically strong and moisture proof. The leads are well extended below the eaves to give ample creepage distance to ground under any weather condition, the porcelain tubes serving to protect the cambric from the weather, porcelain being used for this purpose as the best and most reliable material known at this time. The lower ends of the leads in the tanks are sealed into the tubes with an oil-proof cement which prevents the cambric insulation from "wicking" out the oil.

The switch is made weather-proof by closing the spaces between the tanks on the sides and the bottom with heavy galvanized iron securely held in place by bolts, and by placing over the top a two-part roof of the same material sufficiently large to give ample clearance. For convenience of inspection the roof sections are hinged at the ridge pole, and either side may be raised as desired after loosening a few thumb screws. The weatherproofing was given most careful thought, and it is claimed to be impossible for rain or snow to enter the switch housing, either when falling quietly or when driven by high wind. The housing is designed to permit of circulation of air, thus keeping the tem-



perature of the air within it about the same as that of the atmosphere. It is expected that the oil will absorb more or less moisture from the atmosphere. The insulation is designed to have a high factor of safety even with oil of very low insulating value.

As an insulation test this switch was erected and connected to a 50,000-volt line as follows: while the switch was being erected rain commenced falling, but as it was desired to get as complete a test as possible the work was continued in the rain; the tanks were filled with oil and the switch was connected to the line ready for the test. The pressure was then raised to 60,000 volts and held at that point for 10 min., a separate generator being used for this purpose. The line was then cut back into regular service at 50,000 volts, which was maintained on the switch continuously for 20 days. Rain was falling steadily during the installation and continued to fall steadily while the 60,000-volt test was being made and for over 24 hr. thereafter. Following this rain and during the 20-day test there were a number of showers accompanied by high winds, and one storm which lasted over 12 hr. During all these rains 50,000 volts were maintained on this 30,000-volt switch, with a generating capacity of over 25,000 kw. to hold up the voltage; but notwithstanding the fact that this was nearly double the voltage for which the switch was designed



there was absolutely no indication of distress or weakness at any point. The switch was tested on the lines of the Kern River Co., at Los Angeles, Cal.

August H Kruesi (by letter): The desirability of placing high-tension bus-bars, wiring, disconnecting switches, horn gaps for arresters, etc., out of doors is forcibly called to the attention of the designer in dealing with voltages above 33,000 on account of the very large clearances required for the higher potentials. A year and a half ago this lead to a design in which practically all high-tension wiring is placed on the roof of sub-station buildings, as in Fig. 1, herewith, showing the development of special

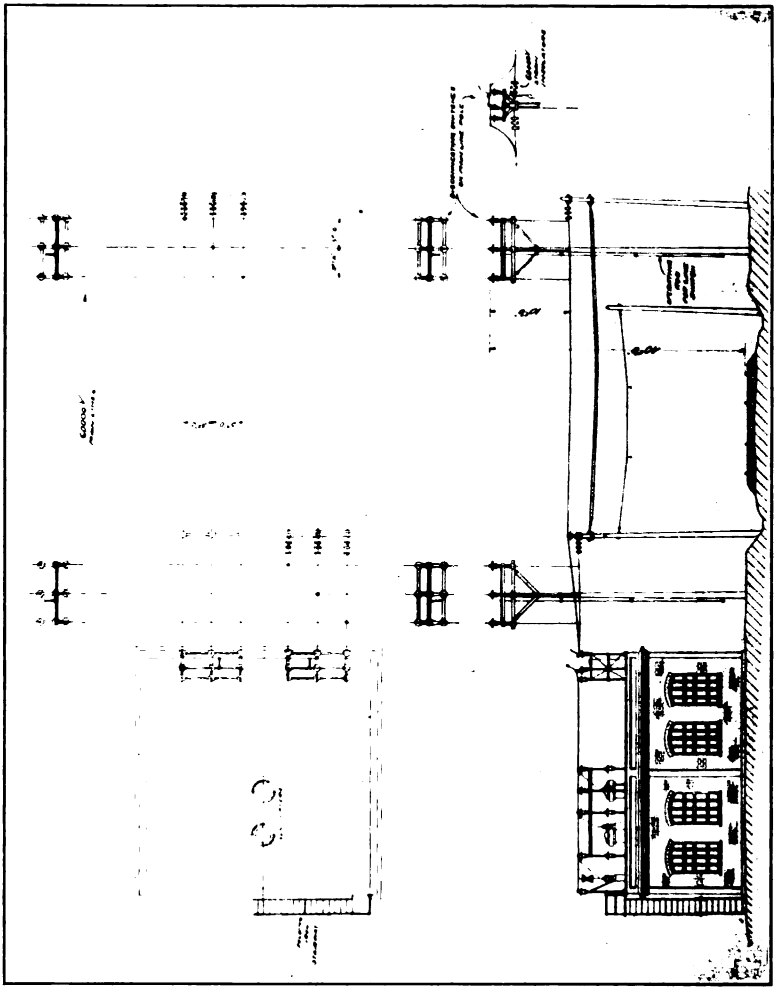


FIG. 1.—General arrangement of 60,000-volt converter sub-station and lines

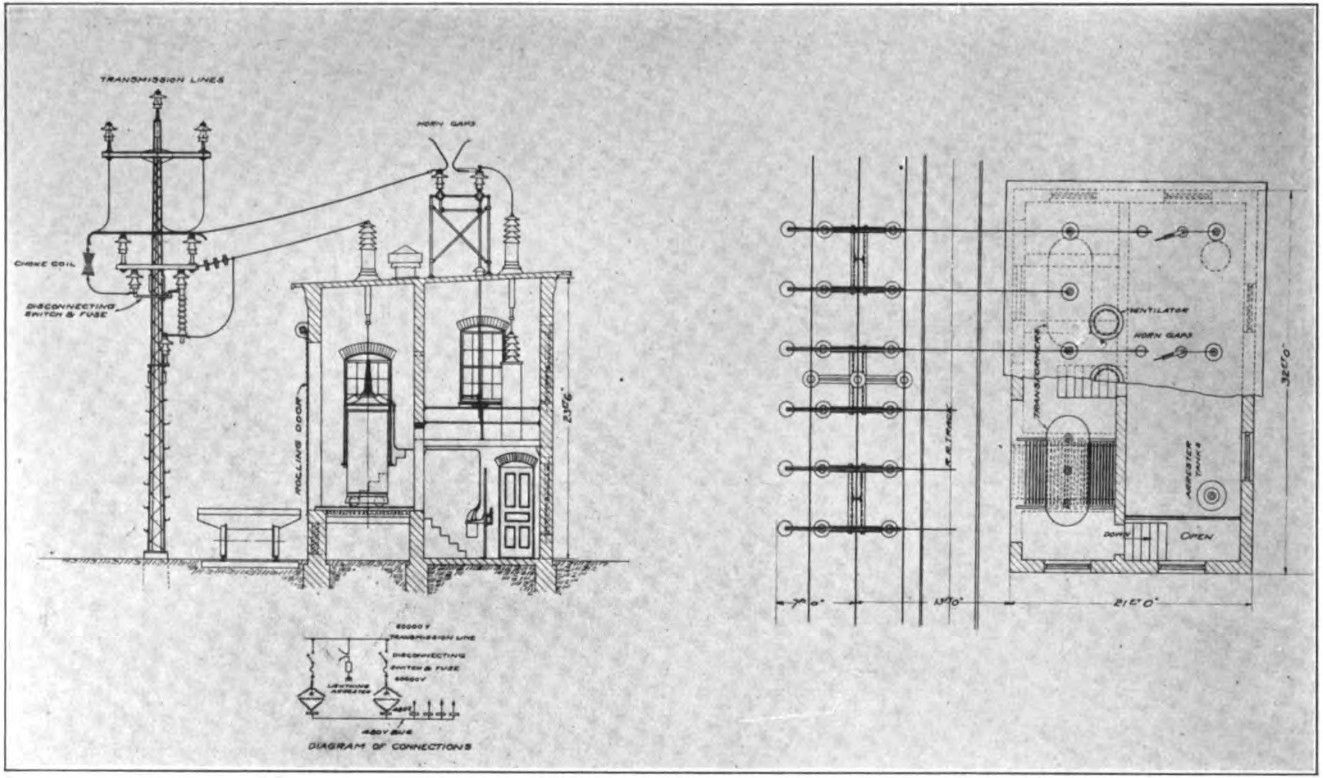


FIG. 2.—General arrangement of 200-kw., 60,000-volt transformer sub-station

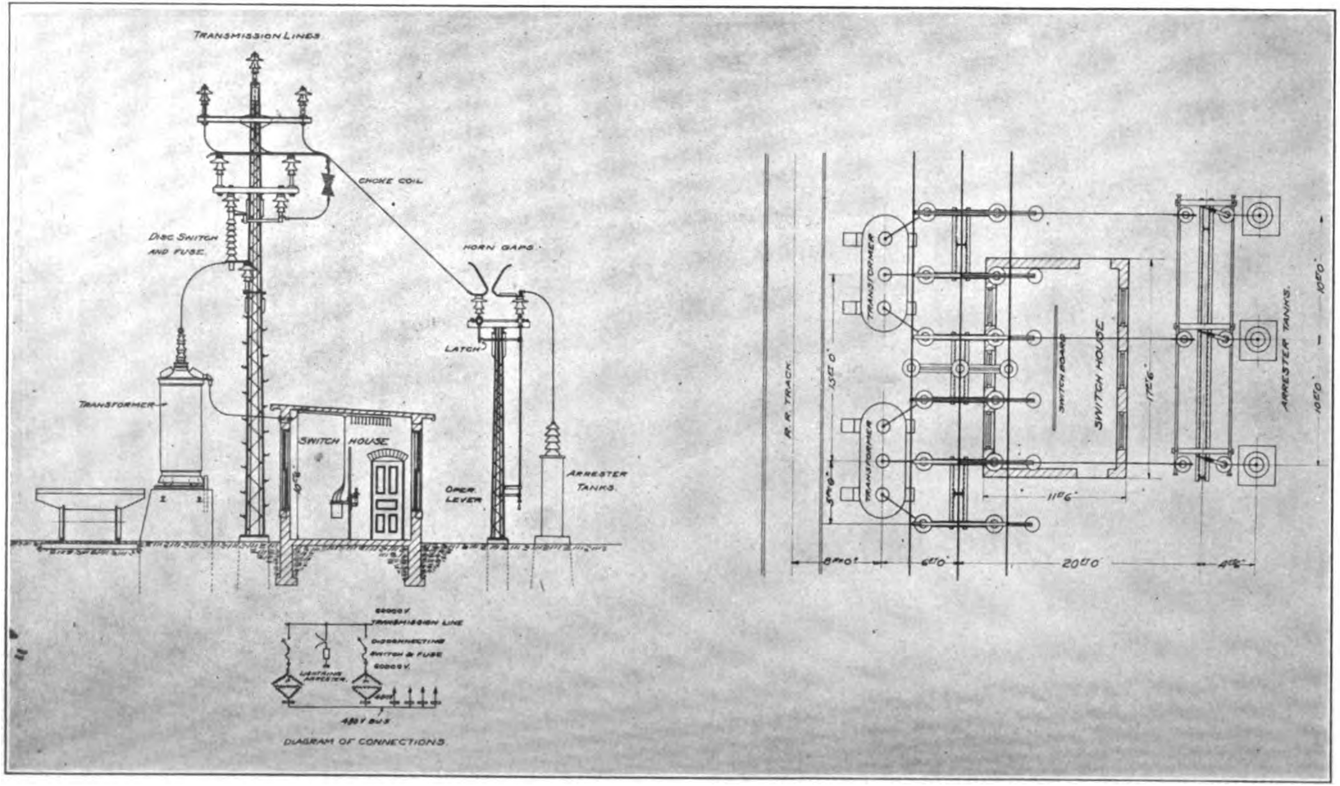


FIG. 3.—General arrangement of 200-kw., 60,000-volt transformer sub-station

weather-proof disconnecting switches for operation from the floor, roof-entrance bushings, etc. Wherever a building is used for the apparatus this roof construction may be considered superior to mounting horn gaps, bus-bars, etc., on a number of poles. Ground space is economized, appearance is improved by reducing the number of poles, and the object of the poles; namely, to raise the high-tension wiring and switches to a safe height, is accomplished while the apparatus is not rendered so inaccessible as when mounted on poles. In fact it is more accessible than if placed inside in the upper part of a much higher building. The horn gaps and disconnecting switches may be operated from the inside of the building. The entire construction is suitable to all climates. Where converters, or other moving apparatus requiring attendance, is to be used, I consider this construction of the outdoor type to the extent indicated, very desirable.

The advantage of making the transformers weather-proof and placing all apparatus except the low-tension distributing switchboard outdoors becomes more apparent in the case of small high-tension transformer stations, which need only occasional attendance and may be protected by fuses on the high-tension side. The fuses require considerable clearance and may well be placed outside. In general, such stations will require some low-tension switchboard equipment, so that a small building will usually be necessary. A relatively large increase in the size of building is required to house the transformers. The use of fuses and the placing of recording watt-hour meters in the secondary circuit eliminate current and potential transformers and make a simple installation possible. Figs. 2 and 3 show comparative designs for a 200-kw. transformer sub-station. It is estimated that steel poles, a fire-proof brick building, and the best construction in all other respects, would show the following approximate costs:

Comparative estimates, 200-kw. transformer sub-station.
One transmission line, no high-tension oil switches.

	Indoor	Outdoor.
Two 100-kw., 60000/480-volt three-phase oil-cooled transformers	$ 5200	$ 5600
Switching equipment, insulators, one lightning-arrester Two 480-volt transformer panels Three 480-volt power feeder panels One 480-volt lightning feeder panel	3307	2847
Freight, installation, wiring of apparatus	1330	1250
Steel poles, cross-arms, and concrete bases	252	386
Building, piers for transformers, excavation, grading, etc.	2740	1022
	$12,829	$11,105

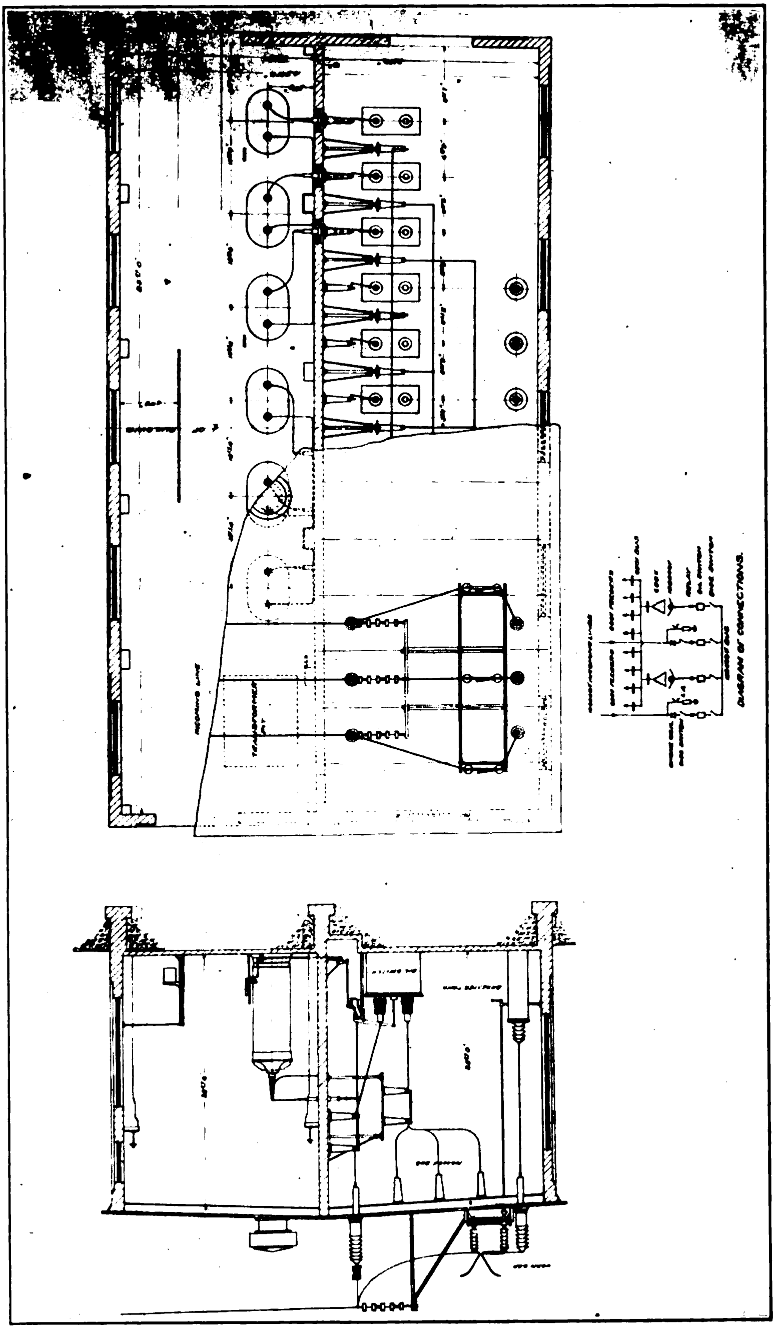


FIG. 4.—General arrangement of 2400-kw., 100,000-volt transformer sub-station

The outoor construction shows a saving of $1724, or 15 per cent. On the other hand, the ground space required is about 20 per cent greater and the actual amount saved is so small as not to be a determining factor.

It would appear that the higher the line voltage to be dealt with the more advantageous outdoor construction should prove. By way of comparison, and to extend the comparison to much higher voltages than those covered in Mr. Randall's estimates, Figs. 4 and 5, showing designs of both types for a 2400-kw. sub-station at 100,000 volts, are added, together with the following approximate estimates:

Comparative estimates, 2400-kw. transformer sub-stations.
Two transmission lines with high-tension oil switches.

	Indoor	Outdoor
Six 400-kw. 100000/600-volt three-phase, oil-cooled transformers	$25,800	$27,750
Switching equipment, insulators, Two lightning-arresters, as per sketches Two incoming line panels with high-tension oil switches Two low-tension transformer panels complete Six power feeder panels complete Two lighting feeder panels complete	12,029	13,739
Freight, installation, wiring of apparatus	5700	5625
Steel poles and cross-arms, including concrete bases, steel framing on roof	104	433
Building, piers for transformers, excavating, grading, etc.	12,041	5870
TOTAL COST	$55,674	$53,417

The indoor estimate includes a 15-ton hand-operated crane and runways.

The small difference in cost—$2257, or 4 per cent—would not be decisive in any case, but the real difference in cost is masked in this design by the use of oil switches, not only for the transformers, but also for the two transmission lines as well, and a building of considerable size in either case for these switches. The use of outdoor oil switches or fuses would make the building much smaller and eliminate 24 line entrance bushings. The outdoor type of installation is, therefore, dependent for a satisfactory showing on the placing of all high-tension apparatus out doors. Merely locating the transformers outside does not accomplish very much in a large station, and, on the other hand, the oil switches may be considerably increased in cost and still show a substantial saving for the outdoor construction. Here again, as in the small station, the use of series relays for the oil switches, air-insulated choke-coils, and instruments on the low-tension side very materially simplify the arrangement.

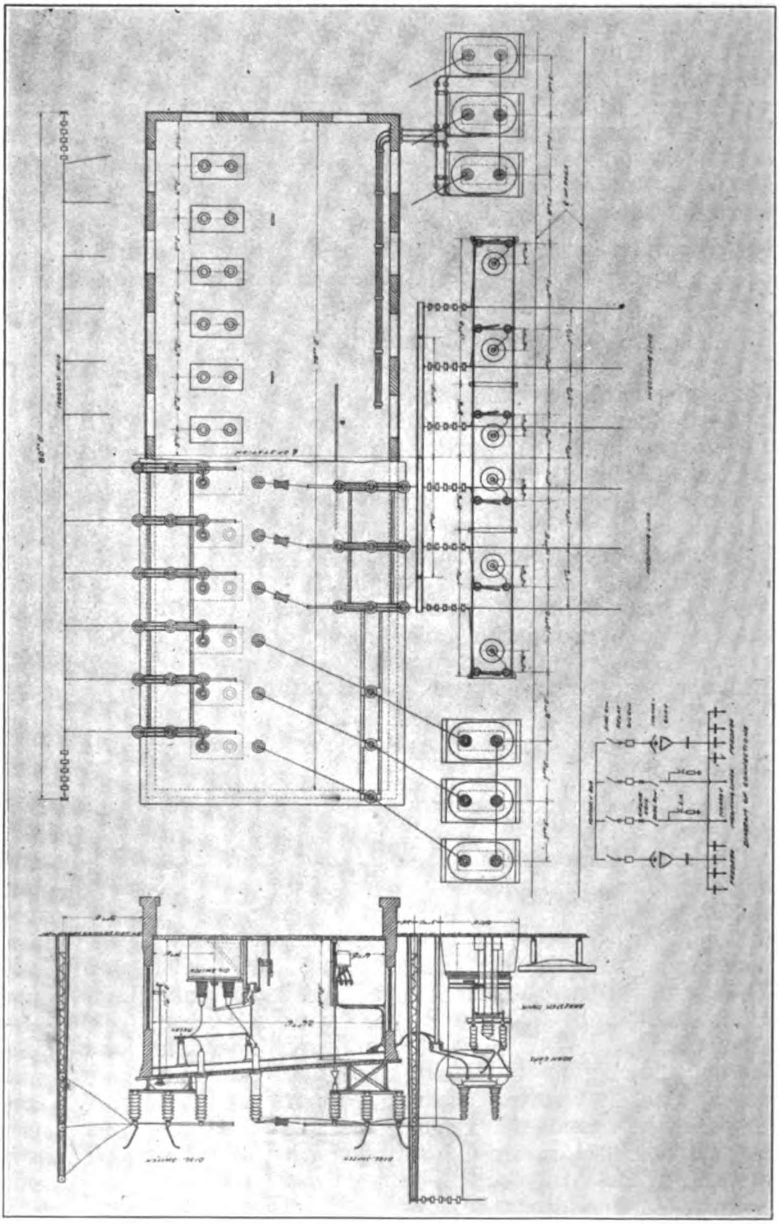


FIG. 5.—General arrangement of 2400-kw., 100,000-volt transformer sub-station

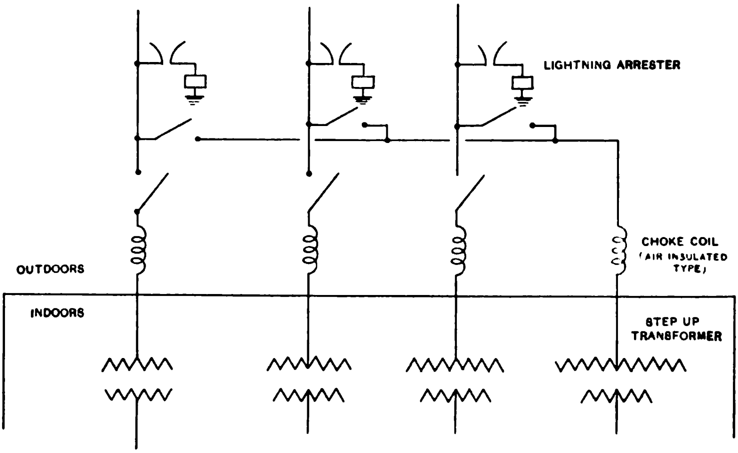
The necessity for making repairs on the spot may often determine the type of construction. A building covering all apparatus would generally be equipped with a crane, and the facility for repairing is a distinct advantage of the indoor ·construction. Exposing disconnecting switches to the weather will generally require a more expensive and complicated type of switch to avoid trouble from sleet and to insure safety to the operator. To work an ordinary knife-blade disconnecting switch indoors at 100,000 volts, a dry pole of about 16 ft. in length is considered necessary. To work a switch outdoors at the higher voltages in all kinds of weather, it seems imperative that a grounded metallic mechanism be used.

D. Kos (by letter): The interesting subject which has been treated in Mr. Randall's paper apparently thus far has been receiving attention only in America, as to my knowledge no outdoor high-tension switching equipments have been installed by European firms. Though at first sight the proposition looks very advantageous, there are a few points on which I would like to make some comments. When comparing the estimated costs for an indoor station and an outdoor station, it appears that only $200 is set aside for weather-proof coverings of oil switches, while it is estimated that the transformers can be made weather-proof for $1,000, or 6⅔ per cent more. It seems to me that these estimates, especially the first one, are somewhat low.

In addition, for outdoor service a heavier type of insulator must be used, and also an increase of cost must be allowed for series transformers and choke-coils. The outdoor structure is made of wood, which is rather a short-lived material at best. For reliability after a certain number of years from the time of construction, this certainly cannot be compared with inside construction work where no use has been made of wood as a building material. Here we have again the same comparison that was discussed rather often a few years ago when the advisability of using steel transmission towers or wooden poles was considered. Nowadays the general engineering opinion seems to be unanimous in favor of steel towers for very high voltages. The use of a wooden structure for an outdoor switching equipment for very high voltages cannot therefore be considered for a first-class job. These considerations largely alter the aspect, and when the outdoor station will be again estimated in accordance with the above the real difference of cost will probably be rather small.

But even if this difference of cost might amount to, say, more than 10 per cent, it remains to be considered, at least for the generating station, whether an indoor station should be chosen under any circumstances, as the advantage of repairing and overhauling during all conditions of weather outweighs a rather considerable extra expenditure. For sub-stations of small importance, however, Mr. Randall's suggestions should be carefully considered, as here the cost of switch gear per kilowatt is considerably higher than in the case of large sub-stations, so that the question of saving money versus decreasing facility of repairs assumes quite a different aspect in the two cases. For the generating station, the money saved per kilowatt is a minimum and the importance of reliability and facility of repairs is a maximum, so that at least here an outdoor station seems to be out of place.

It should be added, however, that though it be less desirable to install outdoors the transformers and other oil-filled apparatus, this objection does not hold good for bus-bars and plain disconnecting switches. For lightning-arresters it may even be an advantage. Outdoor stations, to the extent that they are used by Mr. Mershon in the Niagara, Lockport and Ontario Power Company, do not seem to have any disadvantages; but whether it is good engineering to go further along this line, as suggested by Mr. Randall, may reasonably be doubted, except for small substations. For extreme high voltage the auxiliary apparatus, as oil switches, series transformers, oil-choke-coils, etc., become so cumbersome, voluminous, and costly and introduce so many new danger points in the system, that it is time to consider whether it is not better to do away with all of these as much as possible, and place all switches and instruments on the low-tension side only. For choke-coils ordinary air-insulated coils could be used outside and the end windings of the transformers should be reinforced an extra amount. The high-tension part of the switching equipment becomes therefore as shown herewith.



This switch shows three outgoing lines without oil-filled apparatus on the high-tension side and one spare transformer which can take the place of any of the other three. To simplify the sketch, the scheme has been shown with one line instead of three lines per feeder.

The arrangement is simple and without unnecessary vulnerable points on the high-tension side. The only objection that can be raised is that there are no series transformers on the high-tension side, so that no separate protection of transformers can be applied according to the Merz and Price method. If desired, the transmission line as a whole, including step-up and step-down transformers, can be protected according to the Merz and Price system, provided that both sets of transformers are connected in the same way; for instance, Y on the high-tension and delta on the low-tension side.

DISCUSSION ON "FUNDAMENTAL PRINCIPLES OF INDUSTRIAL EDUCATION." NEW YORK, APRIL 16, 1909

(Subject to final revision for the Transactions.)

Harry Barker: All of us, interested in educational problems, welcome any broad exposition of the aims of industrial education, and of the development of courses that will appeal to the good sense and democratic ideals of the American people. It is fortunate that Dean Schneider has diverted our attention from the details of mere "industrial training" to the broader aspects of "industrial education." When we discuss specific curricula we easily get into fruitless disputations over the distribution of attention between cultural subjects and practical training.

We admit the need of improving the schooling of the coming generations, not only of mechanics and artisans, but also of business and professional men. The first group seems to need a better grasp of the possibilities of some trade that will yield a living, a better introduction to certain ideals of that living, and a cultivation of the imagination to illuminate and inspire the ideals. The younger members of the second group need a closer contact with many practical things and more knowledge of workers, and the conditions under which work is actually done.

The broader the view we take of industrial education, the more comprehensive becomes that term, until finally it stands as one expression of a tendency of the whole system of American public school instruction. The educational method of the future seems likely to become, as President Eliot has so well said, a teaching of how to do by doing—not by reading—an education that is more than memory training. In making courses for future mechanics and artisans, the effect on possible courses for future business and professional people may well be considered at the same time. There seems, in fact, no need for a strict classification of the education of such classes.

The poorer a child's parents are, the more utilitarian needs his education to be, that he also may quickly become a breadwinner. This means a most practical equipment for advance at some trade, and a corresponding lesser emphasis on the so-called cultural side. The more money and time there are available for the child's schooling, the greater the attention we can pay to this side, and the later perhaps can we postpone the utilitarian training.

Two ideas should stand out clearly. First, with the poorer children we should not utterly neglect art, literature, civics and the awakening of the imagination to throw color about dull work. Secondly, with the children in better circumstances, we should insist on attention to more manual or industrial training, not stating exactly how or when this should come. This will help to make better citizens, broadminded workingmen, and more sympathetic business and professional people.

A few words on the relation of this training to that of the future professional men, especially engineers. Most such young men must attend college. Under the inflexible entrance requirements which we must unfortunately expect for many years to come, these popular industrial courses cannot develop literary, historical, and mathematical subjects to such an extent that a student completing a machinist's course, say, would be admitted to the freshman year of a mechanical engineering school, no matter what his ability and inclination. If ambition urge him on, he must be able to continue under some coöperative plan to complete the studies that satisfy the entrance requirements. The work and study for becoming a desirable wage-earner will help to make him a good engineer, but it cannot prepare him for higher education through the usual channels. Therefore, teachers in all industrial courses need to be especially alert, so that a child who exhibits exceptional ability, inclination, dexterity, and ambition, may be encouraged to aim at something higher than a mere occupation. Perhaps in many cases the poorer boys can be helped to begin a college preparation without the loss of a year or more in first completing the regular trade course. A comparison of actual and proposed industrial courses and of standard college entrance requirements seems to show that this is the only way in which the statement near the close of Dean Schneider's paper may be fulfilled. He says:

> It must be evident that with this system in general operation in the public schools, admission to the university would be by natural selection.

One possible effect of the spread of industrial courses will need to be guarded against; that is, the drawing into wage-earners' courses of boys who do not need to sacrifice the greater benefits of present and future high-school training—boys who do not really have to earn as they study, or who do not have to become wholly self-supporting at, say, 17 years of age. It seems a reasonable rule to impose that every student should be kept from making greater concessions to immediate circumstances than are imperative. The great number of applicants for entrance to the few industrial school courses now in operation seems to indicate such a tendency.

There is one point on which Dean Schneider ought further to inform us. He states that 17,000,000 school-children have to go to work as soon as the law allows them. This is 95 per cent of his estimate of the school-children of the country. In the short time available I have not checked these figures thoroughly, but Dean Schneider's source of information does not seem to agree with the U. S. census reports. In 1900, of all persons in this country 10 to 14 years old, 80 per cent were in school, and of all persons 15 to 17 years old, 42 per cent were in school. The deduction is that less than half the school-children went to work at the minimum legal age. It is noteworthy, too, that these percentages are found 10 to 12 per cent more favorable, to the children in manufacturing states and less favorable in states like Virginia, South Carolina, Oklahoma, and Arizona, where there is less manufacturing. In this connection it is interesting to note that in 1900 only 24.3 per cent of all persons in gainful occupations in this country were in manufacturing and mechanical pursuits. This incidentally supports Dean Schneider's contention that the courses must be broad rather than special, so far as the public school teachers are concerned.

The best educators demand that all possible attention shall be paid to preserving the " play-spirit " of those who come under any scheme of industrial education. It is hard to give them as much training as is needed without filling their days and months so full of work that they lose the opportunity, and later the ability, to utilize those relaxations and recreations that are wholesome and refreshing for the body and the mind. Are we justified in taking a boy of from 13 to 16 years of age, and working his mind and body for six days a week throughout the year, with a scant vacation of two weeks? What comes from the lack of air, sunshine, and fun during the years of adolescence? In reply to such cautions we are often told about the relief and relaxation that come by the mere insertion of class hours between shop-periods. That is undoubtedly true to a certain small extent, but by a little more attention on such a point, the production of a still better kind of " civic units ", as Dean Schneider says, will be possible.

The spread of " industrial education " may be slow, but there is an immediate field of work needing attention. Success here will pave the way for the industrial courses. Our schoolboys need *systematic* watching to see what abilities are cropping out; they need to be put to work to prove or disprove the existence of natural bents. Those now best able to exercise such surveillance are teachers in public high schools, but some of us feel that they are not quite properly prepared for giving the most intelligent attention and advice. A great and increasing number are college graduates with some knowledge of the natural sciences, and often having had intimate contact in college with engineering students. Such teachers will be able to grasp the desired methods easily, and they have some excellent pedagogical associations through which they may be reached.

Arthur D. Dean: A great deal of interest is now being taken in the subject of industrial education. It presents a newer phase of education. In the past we have been confining ourselves to the "citizenship" idea, a civic idea which has always held true and always should hold true; but we are bringing in, as we should, the self-supporting and economic purpose in education.

President Butler thinks it is a grave error to set vocational training and liberal training in sharp antagonism to each other. He says:

> The purpose of the former is to pave the way to some appreciation of the latter, and to provide an economic basis for it to rest upon. The

equally grave error of the past has been to frame a school course on the hypothesis that every pupil was to go forward in the most deliberate and amplest fashion to the study of the products of the intellectual life, regardless of the basis of his own economic support.

Dean Schneider says that education is very largely, but is not entirely, a public function. I believe that it is the duty of the state and of local communities to carry on industrial education. Of course private institutions can train their own workmen, but it is primarily the duty of the state to educate its own children. Dr. Draper, Commissioner of Education of the state of New York says that this plan is the only one which holds out an equal chance to everyone; it cannot, in the nature of things, be left to private enterprise. It cannot be dominated by any forces which are in the least exclusive. American workmen are not willing to depend on philanthropy; they will not widely accept the training schools set up by the manufacturing corporations. They are entitled to much the same rights as those that are already granted to the professional and employing classes. They know that they are entitled to equal educational opportunity and will exact what belongs to them. Whatever is done they want done so completely as to command the respect of the best skilled workmen. They will tolerate no false pretense about mechanical skill, but they will be glad to shorten the time in which their boys may become real journeymen. In any event, they know very well, at least their leaders do, that when these things are so they will have to accept them. All this can come in no other way than upon the basis of, and in association with, the public schools.

The New York State Education Department is encouraging local communities to avail themselves of the new law relating to industrial and trades schools. The state of New York is committed to the policy of industrial education. The Legislature of 1908 passed a law providing for the establishment and maintenance of general industrial and trades schools in cities and in union free school districts. For each of these schools which has at least 25 pupils and employs the full time of one teacher, the state will make an annual allotment of $500.00 to the Board of Education and an additional $200.00 for each additional teacher.

Those that are charged with the carrying out of this law are not committed to any one plan. There are several excellent plans. Dean Schneider's plan is only one; the public trades school, without coöperation with the factory is another. It is too early to prescribe rigid general rules to which all must conform. For the present each community will have to be treated as an individual community, and for some time educational necessity will demand plans flexible in nature, plans that can be modified as the need appears for changes based upon a large experience.

I have spent the last 9 months travelling over the state of New York and have met hundreds of teachers, many manufacturers, and public spirited men and women. I have yet to meet opponents of the new movement. The State Education Department recognizes that these industrial schools must be flexible enough to provide: first, for those that can attend school all day; secondly, for those that work a part of the time in order to earn a living but can afford to go to school part of the time; thirdly, for those that work all day but can attend school at night.

Industrial education is a new thing to some people in this state. A good many people are asking what the fundamentals are in education and urging that we get back to them. Some school superintendents suggest that the part-time idea is a possible solution of a serious school problem. They lament the fact that large numbers of children are burdened too early with the necessity of bread-winning and that they are forced into it with no suitable general training, and not sufficient mental or physical maturity. A certain number of manufacturers do not seem to favor the part-time idea; they say that they do not want to be bothered with boys and girls that will work but half a day in the factory and go to school the other half.

The technical difficulties in the way of maintaining a half-time system in all lines of industries are evident. I can see how the plan might be successful in Fitchburg, and I can see how it might be a failure in the paper making and textile industries in New York state.

Probably in the future we will rise to our opportunity either through state laws, force of public opinion, or individual willingness on the part of manufacturers, to have a system of continuation schools similar to those of Germany—a system that will make it possible for the children to be dismissed from factory duties for a few hours a week in order that they may attend public schools and receive training which will make for true citizenship in an industrial democracy. When this is done I hope to see it a part of the scheme of public school education. The problem of industrial education is a public affair. Of course it includes the interests of the manufacturers, but primarily it is in the interests of the workers. I am perfectly willing to see the public schools take the boys and girls a part of the time and to have the shops take them a part of the time; to have the schools give shop mathematics, business English, shop accounts, mechanical drawing, etc., while the private shops give the necessary shop practice. As a public official, I want to know what the boys and girls are doing in the factory; I want to be sure that the work that they are doing is educational, that the shop schemes are educative ones, that the boy is being advanced in his shop training. I expect that the coöperation between the shop and the school will be so complete that the public school authorities will receive reports of what the boys and girls are doing in the factories, how long they are kept at certain machines, the variety of their work. I believe that true co-operation between the public school and the private shop will be worked out only when local or state school officials are allowed to go through the factory and see how well the work is being done from the standpoint of the development of the young worker. The schools can provide the theoretical work which accompanies the practical knowledge, but for the school to do its share without being sure that the factory is doing its share, is fundamentally wrong.

In this matter of industrial education we are in the midst of a great task. We are working out the basis and the details of the greatest industrial democracy in history. Let us lose nothing of our good humor; let us cultivate toleration of opinion; and let us think clearly, with an open mind.

C. E. Downton: The company with which I am associated has made several attempts to evolve a comprehensive apprenticeship system for trade apprentices. We have a two-year engineering apprenticeship course for technical graduates, and a four-year course for the various trades. I shall speak of the latter course this evening.

The proper training of apprentices for the trades is a serious question with us, as it is with all industrial enterprises. A concerted effort must be made to bring about a comprehensive method that will be universally recognized as practicable, else we shall, in the near future, experience a dearth of skilled mechanics and artisans which will place the manufacturers of this country at a decided disadvantage with those of foreign countries, where this matter has been given attention for years. It will not suffice to train men to handle certain machine tools; they must be given a general knowledge of a trade as well as some mental training that will enable them to use the brain to better advantage. They must be taught to guide their hands more intelligently.

The public schools do not meet the requirements of the trades, nor can they be expected to. The problem is entirely beyond the scope of any public school. The factory must therefore assist the schools through coöperative methods, or the manufacturers themselves must establish an educational system supplemental to the shop apprenticeship courses adequate to the mental development required for each particular trade associated with the product manufactured by them.

This condition can only be brought about by an effort on the part of all manufacturers, each carrying his share of the burden. It would not be fair to those willing to spend time and money in the training of apprentices to have others appropriate the benefits. The distribution of apprentices throughout a large works, left to the care of each foreman, will not bring about the desired results. The apprentices must receive closer supervision than can be expected from the average foreman, whose first interest is large production and low cost; for the tendency would be to keep the apprentice confined to one process for too long a time. Increased production, for which we are all striving, does not go hand in hand with the proper training of mechanics; for under these conditions the boy is apt to become a specialist rather than a master workman.

To carry out an educational scheme to work satisfactorily with such a distribution of apprentices is a difficult task. The work is so varied in character, and the boys are so scattered, that the problem is so complicated as to seem beyond solution. The most sensible and the simplest plan is to provide a separate department in the works where the primary object is the proper training of apprentices. The boys should be under the direct supervision of instructors that have been chosen not only because of their skill as mechanics but also for temperamental qualities and knowledge of boy nature.

An educational scheme suitable to the requirements can be carried out without friction or decrease in efficiency of any of the producing departments. An excellent example of such a scheme is that relating to the Lynn works of the General Electric Company described in the paper presented by M. W. Alexander at the Atlantic City convention in 1908.* We have introduced the Alexander system in our works on a small scale, and it has proved very satisfactory. We have not begun the educational part, but we are contemplating doing so in the near future. We have provided school rooms for the purpose.

Chas. P. Steinmetz: In former discussions the Institute has dealt with the problem of college education, and if the college of to-day is superior to the college as it existed in America eight years ago the Institute probably can claim some credit for it. This year the plan was to cover the educational work outside of the college and that preceding the college. While a number of interesting and important suggestions have been received they do not appear to be a conclusive review of this feature of the general educational problem. They cover a wide field, far wider than any the Institute has ever attacked before, so that in discussing the subject perhaps it will be advisable to analyze the situation first.

Society says that safety requires every citizen to have at least a certain minimum amount of knowledge of the subjects important in daily life, and proceeds to supply this knowledge in the education given by the elementary schools. Every future citizen must be made to acquire at least this minimum amount of knowledge. But preferably the citizen should know a good deal more; he ought to be informed on many other subjects. To those who can afford the time this education is given by the high school and the college, and we speak of men who have gained this broader and wider knowledge as educated men. This, however, is not sufficient for the work of life, but in addition to the general education there must be a training in some particular industry.

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* TRANSACTIONS A. I. E. E. Vol. XXVII. Part II. p. 1459.

If a boy learn the art of brick-laying or boiler-making, we do not call that acquiring an education; it is called learning a trade. If, however, the boy is sent to an electrical engineering school he is supposed to be getting an education. But becoming familiar with electrical engineering is not getting an education; it is learning a trade; and does not differ essentially from the learning of any other trade, as that of machinist. Calling it a profession, is merely giving it a different name. The work of our electrical engineering colleges is twofold: they devote the first two years to completing the general education, and the last two years to teaching the trade—or profession, if this term is preferred, of electrical engineering.

When discussing the education of an engineer, there should be kept in mind these different and somewhat antagonistic phases in the preparation for life's work: 1. The education which gives general information on all subjects on which the human being should be informed, which has the effect of broadening the mind. 2. The training in one particular subject, whether called trade or profession, which of necessity must be narrowing, as it deals with one subject and devotes all attention to that. Though this special training lowers the ability to judge impartially of the relative importance of things, it is necessary because it is impossible for one individual to master the details of more than a very small part of human knowledge. Therefore, in order to reduce as much as possible the harmful effect of its narrowing action, we must have as broad a general education as possible. Now, since we do not call the learning of the trade of boiler-maker or blacksmith an education, we have no right to call the special instruction in electrical engineering, in architecture, etc., an education. The term education can properly be applied only to general and broadening instruction, not to the specific training in a profession or a trade. Though this training is necessary for life's work, it is rather antagonistic to true education.

I agree that it is time now to realize that reading, writing, and arithmetic are not sufficient, that there are other subjects concerning which the intelligent mind—whether it merely receives the elementary education or the education is to be continued to a college course—should know something else, food, shelter, clothing, etc. If this is called industrial education it is legitimate, and probably the educational system of the country should be modified. But the teaching of a trade is not within the purpose of the elementary school: the time of study in the elementary school is altogether too short to withdraw any part from the broadening effect of general education to devote it to the learning of a trade or business. If this be the purpose, if industrial education mean converting the elementary school or the high school. into a trade school, or a combination of trade schools, it is a serious, a vicious matter.

Let us take up the second subject, the learning of a trade, or the studying of a profession, whichever it may be called. In this the college fails to a considerable extent by being too theoretical; the ordinary apprenticeship fails by being only practical and not theoretical. In learning a trade we must consider that there is both the practical side and the theoretical side. Theoretical knowledge and practical experience are both required by the brick-layer or the boiler-maker as well as by the electrical engineer or the architect. The weak point of our present methods of preparing for life's work is the failure to supply the proper proportion of both theoretical knowledge and practical experience. In the college education, energetic attempts are made to supply the deficiency of practical experience, either by introducing more or less inefficient shopwork in the course, or preferably by an alternation of the theoretical training in the college with practical experience in the factory. The same conditions probably also apply to all the other professions and trades. But the college takes care only of a small fraction of the educational work of the country.

Thus far consideration of all the other educational agencies has been almost entirely neglected by the Institute. It is important for the future development of the country that the various agencies of education should coöperate—the college, the trade schools, correspondence schools, apprenticeship courses, etc., and that the proper assistance is given them by us.

It is only a very small minority of young men that can get a general, extensive education in high school and college. The majority have to learn a trade to earn a living and are confined to the limited education of the elementary school. Where they desire to advance, to get a broader education and learn a profession higher than the trade which they have acquired, they have to look to the trade schools, industrial schools, and correspondence schools. By these an enormous work is being done in the industrial cities of the United States. It is a work that cannot be done by a college. At present we have no systematic provision for the education of young men whose necessities have thrust upon them the need of earning a living. Here the supervision of the Institute should be exerted, and it is the field which I consider offers the greatest promise for the Institute's activities.

W. S. Franklin: Professor J. McKeen Cattell has recently said* that perhaps it would be well for us to " scrap " our entire educational system and organize it anew. Being inclined to the same opinion, I would ask Dean Schneider why he says, parenthetically, that no displacement of the present high-school course is contemplated in his scheme of coöperative industrial education. For my part, I think that the greatest obstacle in the way of establishing industrial education is the school system that is now fastened upon us. The expression " educational mill " has been used by one or two of those who have discussed Dean Schneider's paper; I think it would be more fitting to use the expression "educational windmill"; for I believe that nearly all serious-minded men are convinced that our present system of education accomplishes but little. I do not mean to apply this term educational windmill to a narrow group of educational institutions, but to all alike; and I will attempt to justify the expression by referring to some of my own work.

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* *Popular Science Monthly*, March, 1909.

I have been simplifying my instruction every year for many years. Last spring I taught elementary mechanics to 190 freshman engineering students in the simplest way I knew; in particular, I discussed minutely the practical aspects of work and energy, giving what was intended to be a thorough drill in problem and laboratory work. At the end of the half-year I gave this problem:

> A cart moves due northwards at a velocity of 6 ft. per second. A mule pulls straight northwards on the cart with a force of 90 lb., and a man pushes straight downwards on the cart with a force of 180 lb.; how fast is the mule doing work and how fast is the man doing work?

Of the class, 43 per cent calculated that the man was doing 2 h.p. and the mule was doing 1 h.p. Now I do not consider it the fault of my own teaching that 43 per cent of the class should be so lacking in appreciation of the practical aspects of a problem of this kind. I believe the fault lies in that most of our instruction in elementary school, in secondary school, and in college is too highly elaborated; in brief, that we teachers persistently ignore the plain and simple and fundamental aspects of things. Educators have apparently reached the point where they go through motions and ignore results. I certainly believe that a first necessity in the establishment of an effective system of industrial education is to ignore what professional educators have to say on the matter.

I am one of those who believe that our common-school system should be revised from beginning to end. And I think that the vague idea as to the desirability of "keeping children in school", which has been conceded by nearly every speaker this evening, is ridiculous. This concession does not seem to me to be based upon a clear appreciation of the value of a common-school training; it appears rather to be a concession to popular pride in the common school as a thing which sooner or later is destined to educate all of us so thoroughly that no one will be obliged to work. That very certainly is the spirit of the common-school system of to-day, and it is the essence of the popular belief in the system.

It seems to me that anyone who has a keen appreciation of the tremendous importance of industrial education must thereby have acquired a degree of contempt for our present system of education. Of course no one in his right mind wants to put boys into shops and work them to death—although many men not in their right minds not only wish to do this but actually accomplish it on a grand scale—but young boys must be given something to do that will develop them; that is certain, and many of our most thoughtful men and women are beginning to realize that the common school does not meet this condition.

What, essentially, is any great industrial establishment, the Bethlehem Steel Works, for example, but a school. For unless men are trained to do the work our industries cannot continue. Every workshop and every industrial and trade establishment in the country, to the extent that it is a school, should be used as such. I believe that the proper utilization of the conditions of trade and industry, especially in our populous centers, in a rational system of practical education is the most important educational problem of to-day, and I believe that its solution lies in an intimate coöperative organization of the common-school system with every industrial and trade establishment where boys can be properly employed. In a practical sense nothing has educational value but work, and nothing else but the actual conditions of our practical life can shape the coming generation for their work in the world. It is, I believe, extremely absurd to attempt to elaborate an artificial substitute for industrial conditions in the detached manual training school or in the detached industrial school, except to a very limited extent and as a rudimentary beginning in the initial training of the youngest students.

Many men seem to be shocked at what they consider the materialistic point of view of those that advocate steel-mill and cotton-mill versus windmill education; but let these men consider whether a materialistic point of view may not after all lead us infinitely further and higher than any fanciful system of windmill education.

John Price Jackson: The great educational departure that is being tried at Wisconsin has not been touched upon yet at this meeting, though in many ways it is one of the greatest experiments in education in progress. Under the direction of the state and the University of Wisconsin, Director Louis E. Reber has established extensive courses which are intended to reach all classes of people in all walks of life. Thus the state sends qualified teachers to manufacturing establishments to teach classes of an industrial nature, or to other communities to teach such subjects as may be called for; correspondence, special classes, educational trains, etc.—all are utilized. I do not know the value of this movement, but there seems to be no doubt that it is in the right direction.

The great bulk of our young men and women, after they leave the public grammar school, cannot go to any other school; a few only are able to go to higher grades. My feeling is that, in the early years, the schools must adhere closely to the "three R's" which form good practical education. The pupils must be taught the proper use of the mind, hand, and eye; how to build up a good body; and to appreciate some of the higher expressions of life and thought. *After* such preliminary preparation, *not with* it, may come specialized training. Many boys because of environment cannot reach the industrial school. Therefore, to reach those who cannot go to a trade school, send a teacher to the factory, or store, or railroad—give them, as well as the more fortunate, an opportunity to develop. Dean Schneider's coöperative plans are excellent for the purpose, but they must be applied with such judicious care that they will not interfere with the early school work.

I said a word or two in my written discussion in regard to Dean Schneider's "alternate week" system for college men: it is only applicable to a limited extent. Thus, in hard times especially, industrial or commercial concerns cannot take all the pupils who must later enter the industries or commerce. The school system must give every boy a chance, and, therefore, it seems to me that in its remodeling care must be taken to do the work in a way so facile that it will meet the different conditions of the various communities and classes with which it has to deal. This will require trade schools, schools in the industries and elsewhere, correspondence courses, and other methods, but little time or thought can be wisely given by the pupil in his early years to other than the general foundation training needed by all children.

Otis Allen Kenyon: Education of the young is the greatest and most important problem with which we have to deal. We may possibly go so far as to say that the answer to the "eternal question" as to the real purpose of life is to produce a better generation than the present ruling one. It is a field of endeavor in which every man and woman can take an important part. The education of an individual begins the day of birth and extends over the entire period of active life. For this reason it is most important that all of the early training should be in the fundamental principles, which may be considered as tools with which all subsequent progress can be accomplished; that is, we must prepare our youth for self-education.

Reading is the first requisite, since I consider that most knowledge is acquired by reading. Broadly considered, training in all fundamentals is simply learning to read. Especially is this true of languages and mathematics. I was astonished some months ago to learn that a large percentage of our American born children did not learn to read, and especially so when I found that New York state stood near the top of the list in illiteracy. The natural conclusion was that the city of New York, with its immense foreign population, was the cause of it. Not so. New York City stands exceptionally high. Illiteracy occurs largely in the rural districts of the state, where there has been no foreign influx for years.

In the Scandinavian and German countries such a thing as illiteracy is practically unknown, and I had previously thought such to be the case here. In New York we have a fine educational system in theory with laws to back it up. The law says that all children between certain ages shall attend school, and having these excellent laws we rest contented, leaving their enforcement to the discretion of local authorities. Therefore, illiteracy is the most powerful where it finds least resistance.

This great problem should be attacked at the bottom and all children given a good start in spite of their local surroundings. Their industrial training will take care of itself if necessary. In former times before industrial training schools were heard of, the hand-workers learned their trade as very few do now. For example, old books made on hand-presses reveal work which we cannot equal to-day with the finest machinery. It is true that a comparatively small percentage of the people were skilled artisans in those times, and, undoubtedly, they were a superior class of men such as we now find doing only brain work. Nevertheless the fact remains that the bread-winner must learn his trade whether he will or not; and if equipped with a fundamental education, he will go further and faster.

Our educational system is not what it should be and the trouble seems to be one that is inherent in our form of government, namely, the lack of centralization of power, and, therefore, a lack of uniformity. The fact is that we have no system.

I believe in individualism in the highest educational institutions, but in the lower ones there should be more and more uniformity as we descend the scale. To say that a boy has a high-school diploma means nothing until we have been told what state the school is in, and even then it really means little unless the name of the city or town is also given. It is a fact that our own colleges recognize diplomas from certain high schools and not from others. With such a state of affairs it is little wonder that the best European schools absolutely discredit all diplomas obtained from our public schools. The first step, then, is to obtain a uniform standard of education throughout the country, so that a diploma of a certain grade has a meaning which needs no special interpretation or explanation.

Granted that we have a uniform and well-organized school system, we can then take up the details of what to teach and how it shall be done. What to teach should be decided by the central organization and should be fixed for each grade. How to teach should be left to the teachers, since no uniform method will please all teachers nor suit all pupils, and no good teacher can work well when using a method with which he is not in sympathy.

The most important thing is to have good teachers. Our teachers should not be reservoirs of knowledge; they should be independent thinkers and natural educators. The whole purpose in education should be to awaken a thirst for knowledge and to encourage independent and analytical thinking. Any youth starting out with the thinking habit and a working knowledge of the fundamental principles of his profession will advance to a limit imposed only by his innate shortcomings.

Dean Schneider's idea of coöperation between employers and educators is an excellent one. The public school cannot teach specialties; it must teach the elements which are used to build up the specialties. However, if the school can follow the pupils into the shops where they are learning their trade and show them how to apply their theory, it can do great good.

As Dean Schneider points out, by far the greater share of our children leave school early to earn their living, and, therefore, the public school should consider them first. They should not be taught many different subjects, but rather thoroughly drilled in the most fundamental ones. It seems to me that our schools attempt to teach too many subjects, the result being a superficial education which is sometimes worse than none at all. It is absolutely harmful in some cases to teach things which can never be properly comprehended. Many pupils are ruined by education instead of being bettered. They are taken beyond their depth and given a smattering of this, that, and the other; and when they are through they think they are too well educated to learn a trade. Coöperation between schools and employers is a good thing; but what we need most is coöperation in the schools themselves to produce an efficient and uniform system of public instruction.

Dugald C. Jackson: I wish particularly to call attention to the following sentences found in the paper.

> Under present conditions most of the children who leave the public schools go at once into the industries or stores, and there is no connection whatever between school and shop. The children go to work not because they want to, but because they have to become little bread-winners. Here, then, are many children working in some capacity, and a series of public schools carried on only for those who are fortunate enough to be able to continue in their school work. Since the public school system is the only organized institution capable of dealing with all these children at work, and since the children are also learning a trade and earning money sufficient for their simple wants, it seems that the only complete solution of the problem is a system of coöperation between the schools and the factories for efficiency training and civic training of the young people after they have found their work.

This is a clear statement of the present situation, and it emphasizes the fact that industrial training in this country may rest with the public-school system. At this point I wish again to urge the importance of having the organization and development of industrial training put under the direction of adequate educational bodies. When I say *adequate*, I mean bodies that are not only strong in the educational branch, but that are also well informed as to the industrial requirements. I know of no bodies that meet the conditions so satisfactorily as the faculties of the great engineering schools. While it would be a misfortune to have the engineering schools take industrial education into their curricula, such faculties may wisely be held responsible for the organization and development of the work. This is the procedure which is now going into effect in the state of Wisconsin, where the organization and development of industrial education has been placed by the legislature under the direction of the University of Wisconsin, and the work is being carried out by a department of " university extension " of which the director is a well-known engineer who was for a long time dean of one of the engineering schools. This seems to be already bringing favorable results, though the work has been in progress only a short time.

Dean Schneider indicates that the German continuation school idea, which is supported in Germany under the requirements of imperial law, approaches his ideas of the necessities of the present case. In that case the teachers go to the students, as desired by Dean Schneider, but the coöperative or alternating plan discussed by Dean Schneider is not put into effect. Dean Schneider's plan seems to contain the desirable elements of the German continuation school idea, and it adds thereto other elements. To carry out his idea of *in loco parentis* for the public schools would require endless tact on the part of the teachers, and would doubtless call for a higher average grade of men for teachers' positions, in case the plan could be put into effect. But such changes in the teaching staff would be well worth while, provided they brought the results of increased efficiency and improved citizenship for the youths who must bear the brunt of artisanship for the coming generation.

The " coördinator " plan proposed by Dean Schneider is a novel one. It seems likely to be useful; but better results would probably come from the work proposed to be done by the coördinator if he could give his instruction in an extra half hour at noon or at some similar time during the boy's shop assignment. This might be practicable only in the case of establishments employing a large number of the coöperative apprentices. It will be observed that Dean Schneider himself makes a suggestion in harmony with this criticism, in the discussion of the shoe division of a department store.

I believe that this paper presents ideas which are worth the careful consideration equally of the employers of skilled workmen and the public school boards of industrial cities. The ideas are also of vital interest to the engineering profession, for without skilled workmen to execute their projects engineers would be helpless; and the engineers should properly give careful attention to any plans which promise a better training for artisanship.

A. R. Dennington (by letter): As a factor in industrial education the correspondence system deserves attention, not only for what it has done in the past but also for its inherent possibilities. Considered from the standpoint of adaptability, instruction by correspondence is almost ideal, as the student pursues his usual vocation at the same time that he is studying the principles of the underlying theory. It may be implied by some that in the past the student has spent his time studying some line of work entirely different from his daily task and that as a result the correspondence schools were instilling the spirit of discontent and making employes less efficient. Instead of the machinist studying mechanics or something related to his work, he would be spending his leisure time studying bookkeeping or chemistry, with the intention of giving up all his practical experience and making a new start on the foundation of the few unrelated facts which he had learned. It is of course true that an occasional man is able to achieve signal success by such a course, but he must be regarded as the exception rather than the rule. Most persons that take up correspondence instruction have passed the period of life when they can easily make changes in employment, and when such persons do change there is a certain economic loss. It is reasonable to expect that if the energy expended in preparing for the changes in employment had been expended in making the workers more efficient in their original line of work, the measure of their success would have been greater.

There seems to be an almost universal idea in this country that the work of some other individual is more desirable than one's own, and this makes the man who has spirit and ambition a ready listener to any proposition pointing toward imaginary opulence. The man who has spent years in one line of work is unable to judge accurately of conditions outside of his trade. He may appreciate the crowded condition of his trade and may realize the difficulties in the way of advancement, but he does not realize that the same conditions exist in the occupation he thinks of taking up and that individual success in either case involves more than average ability.

The common defects of correspondence instruction as pointed out above are not insurmountable, and will as time goes on be more or less completely eliminated. Statistics show that the greater number of persons who have been materially benefited by a course of correspondence study have read on subjects related to their previous work. They have used their studies as elements in the process of evolution. The usefulness of the correspondence school depends upon its ability to increase the efficiency of the worker in his employment rather than to incite him to make a change. He should be taught the truth that any line of honest endeavor is honorable, that it merits special study and will reward it. It should then be the aim of the correspondence course to make the plumber a man who will do his work with careful attention to underlying sanitary engineering principles; to enable the farmer to produce more from the same soil without impoverishing it; to give the engineer or fireman in a power plant the knowledge which combined with his practical skill will make possible the more economical production of power. In short it is the province of the correspondence school to improve the artisan and thereby cheapen the cost of production while increasing the economic and industrial value of the producer. Training of the kind outlined is narrow in the sense that it is applied with the idea of developing and directing thought along one line, but experience shows that even one small division of any science or art offers problems worthy the most thorough study.

The absence of any personality in the instruction is an inherent defect in the system. This disadvantage cannot be measured because of the diversity of the effect of the personality of any teacher on a number of pupils, and also because of the different individuality of the teachers. Most of the printed lessons represent the composition of several individuals, and an entire course in any branch represents the work of a small army. There can therefore be no pronounced individualism in the courses of instruction.

In correspondence instruction as in regular teaching work the attitude of the student is very important. Many persons take correspondence courses with the idea that their part in the contract is merely to remain passive and receive in some mysterious manner the dreamed of knowledge and power. There is also a noticeable tendency on the part of some to regard the number of pages covered or the number of subjects skimmed as the only essentials to increased efficiency. These tendencies must be considered in forming any judgment of the results obtained by correspondence instruction. In time they may be reduced, but the change must come rather slowly, as many people are willing to accept the superficial and artificial as the thorough and genuine education.

Herman Schneider: In order to satisfy Mr. Barker's question about the figures used in regard to the children of school age in this country, I quote from a report compiled by Professor Ayer of the University of Cincinnati from the Report of the United States Commissioner of Education:

> In 1906–7 there were 24 million children of school age in this country. Of this number
> 76 per cent were enrolled in the schools;
> 54 per cent were in average attendance;
> 18.5 per cent completed the elementary courses;
> 12.6 per cent entered high schools and academies;
> 3.4 per cent graduated from high schools and academies;
> 1.84 per cent entered colleges and universities;
> 0.67 per cent graduated from colleges and universities.

Confusion may exist in regard to the figures I have given previously, because in some instances I state the total number leaving school when the law permits them to do so, and in other cases I state the number leaving school without industrial training. The report of the Commissioner of Education contains the interesting information that out of 24 million of school age about 63,000 children receive commercial or industrial training in the United States.

Mr. Barker is of the opinion that under this system boys would have no time to play, go fishing, roam the field, etc. As a matter of fact, without this system, as shown by the figures given, the majority of the children would be in the shops throughout the year. It is specifically stated in this paper that the coöperative system contemplates taking the children *after* they have found their work, and giving them further schooling. Under the coöperative system the children would be at school at least every other week; they certainly would have play hours and time to roam the fields, which they would not have were they not in school at all. The coöperative system is fairer to the boy than the present industrial system, which shuts him up in a factory nearly all the time.

Mr. Barker further questions my statement that the coöperative system leads by natural selection to the university, saying that a student under the coöperative system would not be prepared to enter the university. Under the Fitchburg scheme, a boy from the coöperative course could enter college after one more year of High School. If he should show an engineering bent in his shop and school work under the coöperative system, he would in all probability be urged to go to an engineering college, and opportunity would be offered by an extra year's high-school work to enter any technical school. If then the technical school has a coöperative system—as a number of them will have—it ought to be evident that the way is open for any ambitious young man of virtually no financial means to obtain an engineering education, provided he ought to have it.

Mr. Dean says that the coöperative system is not generally applicable, that it could not be used, for instance, in the dairy industry of the state of New York. I would call Mr. Dean's attention to an article in the current number of the *World's Work*, which describes a coöperative scheme whereby the University of Chicago coöperates with the large farms in Indiana and Illinois under a plan by which the students work on the farm during the open season, and attend the university during the closed season. There is a definite co-ordination of the theory of the university with the practice of the farm, and this includes the dairy work. It can be shown that dairy work under a coöperative scheme is just as feasible as machine work under similar conditions. The details of coöperation, however, must be made to suit the peculiar conditions.

Mr. Dean also speaks of the difficulty of getting teachers for this system. This difficulty exists in any industrial education system, if industrial education is to be *real* industrial education. The trouble with most industrial education is that it is not industrial, and that it is not taught by teachers that know industries. Teachers can be found if they are sought. The statement is not more of an argument against this system than it is against any other system of industrial education.

Mr. Dean further suggests that if the coöperative system is put into the public schools—and he agrees that it should be—the schools should be given authority to plan the courses in the shops, and that he would insist that his department plan the courses through the shop. I have been operating a coöperative course in engineering for several years, and am not quite sure that I am as yet capable of planning the shop work of my students. The shop superintendent knows more about this than I do. Since the public schools would have to deal with hundreds of trades, it would take a man of greater ability than exists anywhere to plan all these courses in the shops. The shop superintendent knows more about it than any educator. As a matter of fact, these courses are worked out by consultation between the school authorities and the shop people. Coöperation means coöperation; it does not mean dictation by either manufacturer or school.

Professor Franklin asks what is meant by my statement that no displacement of the present high school courses is contemplated, stating that in his opinion the present high school courses should be "scrapped." I agree with him that most of the work of the high schools should be scrapped, and I think it would not make a very valuable pile of junk. What I mean in my paper is that no displacement of the present courses preparing students for the university is contemplated.

Professor J. Price Jackson says that the coöperative system would not be feasible during hard times when the students would be thrown out of work. When such times arrive, it ought to be obvious that under the coöperative system the students are in school at least every other week. If there is no coöperative system, they are idle every week. Between the two, it seems to me that the coöperative system has the advantage. During the periods of depression the student could, if it is desirable, be held in school all the time, and his job reserved for him at the shop until work is resumed. It seems to me that the coöperative system is specially well adapted for periods of depression, in order to have a check on the youth when there is no work.

The purpose of this paper is to point out two things: first, that the problem of industrial education is so big and comprehensive, that it must be solved by the public school system; secondly, that this must be done by coöperation with the industries for the education of children *after* they have found their work. No arguments have been deduced in this discussion to show that these two propositions have not been established.

The paper attempts to show further that the details for every industry, and for every city, would vary. For instance, the scheme which fits the University of Cincinnati in its engineering college might not fit the Massachusetts Institute of Technology. The details of a scheme that fits the machine industry of Cincinnati might not fit the same industry of Fitchburg, Mass. The details which fit commercial life will not necessarily fit industrial life.

There are many ways in which this coöperation can be carried on. For instance, in the building trades in Chicago there is an agreement between the master builders, the union and the public schools, whereby the apprentices go to school during the slack months in the winter to obtain efficiency instruction. They are not, however, taught the trades in the schools. This is a coöperative system.

The one idea which I am trying to impress upon educators and manufacturers is the necessity for coöperation between the manufacturer and the school for efficiency training and for citizenship training; in other words, to fit the student for the thing he is to do, and for the man he is to be. There is a fundamental difference between a coöperative course in an engineering college and a coöperative course in the trades. In the engineering college, the university selects a number of young men, sends them for a trial period to the shop, where they are finally selected by the manufacturer. In the trades the idea is to take the young men already on their jobs and give them more education. In other words, to take the school to the boy in the shop, and not to take the boy in the school to the shop.

Charles S. Howe (by letter): There are two methods of training industrial workers: through the apprenticeship system and through the trade school. The apprenticeship system is the most obvious and natural method. As the journeyman will work in the shop after he has learned his trade, it seems proper that he should acquire that knowledge in the shop. Manufacturers usually believe this to be the best way because the boy is then under shop conditions while he is learning; he works with experienced men, he gets the shop atmosphere; he learns to do his work so that it will come up to the commercial standard. All this is of great advantage to the young apprentice, and if the conditions are favorable, there is no place better than the shop for learning a trade. It however has some disadvantages.

1 The superintendent may not have a very broad view of the duty of the shop toward its apprentices. If he has not, he will see that each apprentice learns to use some one machine well, and that he remains the greater part of the time at work upon this machine instead of acquiring a knowledge of all the machines in the shop.

2. The smaller shops are limited to one particular kind of work. As a rule it is the coarser kind and hence the apprentice learns only this sort of work. He can not acquire the other parts of his trade in that particular place. Yet under the apprenticeship system he gets at this one place all the knowledge that is required to make him a journeyman.

3. Under the apprenticeship system the foreman is the teacher, but his principal duty is not to teach the apprentices it is to turn out as much work from the shop as possible. When he has spare time he spends it in showing the apprentices how their work should be done. Where the management is sympathetic, where it is the purpose to train the boy in all branches of

the trade, and where a special foreman is employed to teach apprentices, no better system than the apprenticeship method can be found for training the journeyman in any trade.

There are many large establishments which have an admirable apprenticeship system, but the great majority of factories of all kinds do not have such a system, and hence we are not training enough skilled workmen in any of the trades. To meet the demands of the future and to give the boys and girls a better industrial opportunity, it has been proposed to establish trade schools, either under the administration of school boards or under special boards authorized to expend public funds. A few such schools have been in existence for a number of years, and their graduates have been successful. These trade schools, if properly designed and planned, will be in buildings which resemble a shop, will have the same machinery which a first-class shop would have, and the teachers will be men who have been foremen in shops, but who have left their regular work to enter the school because of the higher pay which will be offered. The work turned out will also be of the same kind as that of the shop and will be subject to the same standards of efficiency because it will be sold in the market in competition with other goods. The amount of goods so sold, however, will never be large enough to seriously affect market prices.

The trade school method will train more journeymen than the apprenticeship method. If properly conducted, I believe it will train them just as well as the best apprenticeship system, and in the majority of cases, it will train them better. It will meet the demands of the manufacturers for more skilled workers and it will give the boy or girl who wishes to learn a trade the most complete opportunity of so doing.

V. Karapetoff (by letter): I am favorably impressed with the spirit permeating Dean Schneider's article. There is so much freshness and optimism in it, that one immediately feels new courage and energy for promoting industrial education. The principle of coöperation between schools and industrial establishments ought to be encouraged by all means. The question as to how far it ought to be carried may be discussed later on, when sufficient information and experience will have been acquired.

I am particularly pleased with two ideas in the paper: one is that it is our common duty as citizens of a state or a country to educate the coming generation for a maximum of efficiency, that the duty does not end with paying the school tax. Industrial establishments can help the cause of education by direct coöperation as outlined in Dean Schneider's paper much more and with less sacrifice than by contributions in money.

The other idea is that of interweaving theory and practice so that neither becomes a burden to the student. Practice alone prepares a narrow artisan by its multitude of petty rules and empirical " ways of doing things "; theory alone is barren, being like a form without contents. With the plan suggested, the student is shown how certain results are achieved; at the same time the observed facts are coördinated in his memory by the underlying theory.

G. M. Basford (by letter): Those who are watching the interesting and promising development in the direction of industrial training, and especially those who are in position to realize the great importance of the movement cannot fail to be hopeful of exceedingly important results. This problem is so complicated as to require many different plans for meeting various individual needs. Of all the plans so far suggested, that of Dean Schneider seems to contain the largest number of elements necessary to successful achievements. For large manufacturing establishments producing heavy machinery and involving progress in methods and equipment, progress which at the present time is exceedingly rapid, it is obviously necessary that the school should be taken to the shop. I believe that the plan of Dean Schneider is exactly what is required for such establishments, with one modification, that the part of the development which is generally spoken of as education should in such cases be given at the works of the company. This is going one step further than Professor Schneider has gone.

Alexander C. Humphreys (by letter): The following statements appear in Dean Schneider's paper: "The chief end of education is so to instruct the individual that all individuals as civic units will combine to make the best possible State." . . . "The object of all education is to make good citizens, and the first duty of a good citizen is to earn his own living."

I fully agree that these *should be* the end and object of education, but I am not inclined to believe that we have convincing evidence that these are the end and object of the public school system of these United States. Certainly the results do not furnish such evidence. Some system of industrial education for the training of the masses should be developed to meet this deficiency. At least, the public school system should be remodeled so as to prepare along the lines of maximum efficiency for later specific training for the industries.

As Dean Schneider points out, our public schools cannot be expected to give specific training in all trades, but much can be done in the way of preparation that will apply in a general way to all trades, and more specifically to a few trades. In my opinion, the first step to be taken is in the direction of greater thoroughness in the fundamentals, and especially the "Three R's".

Dean Schneider quotes some one as saying "Under the coöperative public school system, the grade school principal pays much less attention to biology and much more to the boy". I wish this statement could be made truthfully of all elementary public school instruction.

Dean Schneider mentions shop mathematics. The term is suggestive of practical efficiency, but I would like to extend its scope by making it include the simple mathematics required in shop, field and counting house. The every-day mathematics should be better taught in the schools, and especially elementary arithmetic in the elementary schools. I sincerely hope the author is warranted in his belief that the coöperative system can be so developed as to make it generally applicable throughout the United States. Certainly there are great difficulties in the way, and especially in obtaining the coöperation of those engaged in the industries. I fear one trouble that would develop would be the tendency of the professional teacher to attempt to teach where he is not qualified so to do by practical experience. The system to be a final success would have to be the product of evolution, for as yet none of us are capable of preparing the detailed specifications of such a system—we must be satisfied to hold to the good and reject the bad as the practical conditions are met and overcome. In the line of manufacturing, if in any case the green boys and girls could be used to advantage, I should not apprehend any final trouble from the alternating employment of two sets of students. One favorable feature to put against the unfavorable features would be that of incentive to best effort through honest rivalry.

One thing we may all agree upon—in the training for citizenship, and, incidentally, for the industries—our public school system is sadly deficient, and all of us—and we all are concerned either directly or indirectly—should be willing to work as well as talk for reform.

Ralph W. Pope (by letter): There can be no question as to the benefit to the individual, of an industrial education. Even though the person learning a trade may never be required to practice it for earning a livelihood, knowledge of a handicraft will be a source of satisfaction to him throughout his life, especially if he has a natural taste for the particular branch which he has studied and practised. There appears to be, however, considerable doubt as to whether the graduates of industrial schools will follow through life the trades they may have partially learned. A strong social prejudice exists against manual labor, skilled or unskilled, as well as against the confinement and discipline of factory life, which no educational system can overcome. In a comparatively new country the demand for labor of all grades can only be met by immigration. High wages in themselves will not divert the rising generations from their tendency to obtain a livelihood in some other way than working at the bench, not even with the possibility before them of promotion to the grade of foreman or superintendent. Unless some method can be devised to counteract this tendency, the final outcome of industrial education so far as furnishing a supply of skilled apprentices is concerned will simply add to the already overburdened curricula of our public schools.

That this condition of affairs is not peculiar to the present day is indicated by the following excerpt from an essay by Ezra Sampson a minister, editor, and a captain in the revolutionary army. It appears in a school reader published in 1820:

> In the proud and fastidious times in which we live, manual labor of the useful kind is accounted a thing too vulgar for those of the better sort. Many a young gentleman would feel himself dishonored by doing anything called work; and many a young lady would blush to be found employed in an occupation really useful; even though in circumstances imperatively demanding their industry.

It is well to profit by past experience, and for this reason I will refer to the fact that about 1682 Thomas Budd introduced into West Jersey, (the southern part of the present State of New Jersey) the Quaker system of education through which the boys were to be taught:

> Some mystery or trade as the making of machinery, joynery, turnery, the making of clocks and watches, weaving and shoemaking. The girls were to be taught in spinning in flax and wool, the knitting of gloves and stockings; sewing and making all sorts of needle work, and the making of straw work, as hats, baskets, etc.

This system apparently was gradually abandoned, yet I have been told by a neighbor in Elizabeth, N. J. that in his school days (about 1845) the girls were taught shirt-making, and he remembers the teacher's instructions to " fell the gusset to the sleeve, and the sleeve to the gusset." If these "girls" ever made shirts for the family the domestic art has long since been abandoned. About twenty five years ago manual training was again introduced in the public schools of Elizabeth, and has since been abandoned. I asked a pupil of that era if he knew of any instances where the trade learned had been followed after graduation. He could recall but the single example of architecture which is of course recognized as a " respectable " profession. It is evident that a sufficient number of industrial schools have now been in operation for such a length of time as to permit the collection of statistics bearing upon this question, which is: of the number of students learning trades, what proportion have actually followed them in after life?

Sydney W. Ashe (by letter): Dean Schneider's paper discusses the problem of industrial education from a manufacturer's viewpoint. The solution of this problem becomes more difficult where it deals with the employees of an operating company, whose success depends upon all departments moving in synchronism. Where one is attempting to raise the educational status of the employees of an operating company, the work must not in any way interfere with the moving mechanism of the company but must be carried on at such times, afternoon and evenings, as the men are free from their regular hours of duty. The work must be flexible, as the ages of the men range from 16 to 60 years, and their education ranges from that of the grammar school to the college graduate. The work must be attractive, for with the meetings of various other societies, especially in the large cities, the men will not take advantage of such courses and will not attend.

The course must be progressive each year, as there are a certain number who constitute the backbone of the course, who attend almost every lecture, and who must therefore be given first consideration. Most of the men are handicapped by a lack of advanced mathematics which must also be considered. Educational courses for their employees are now being carried on by the New York Edison Company, the Edison Illuminating Company of Brooklyn and the Edison Electric Illuminating Company of Boston, all of which the writer had the privilege of instituting. The method used in carrying on this work was described in detail in the *Electrical World* of May 16, 1908; briefly, it consists in giving an extensive course of experimental lectures on electrical engineering.

The first year, a course is given extending from the elements of magnetism through direct and alternating currents. At certain intervals in the course, radical departures are made from the regular program, Table 1, by the insertion of lectures such as on turbines, for the purpose of arousing fresh interest. The second year the subject of fundamentals is dropped for the time being, and the application of the fundamental principles to the company's methods is taken up. A course of such lectures extends from the coal pile to the consumer. A third season, more advanced principles may be taken up.

The writer had constructed a special form of projecting lantern with large condensing lenses which could be quickly connected

TABLE I.

CALENDAR OF DATES AND TOPICS. 1909.

1. Thursday, Jan. 7. Magnetism.
2. Thursday, Jan. 14. Electromagnetism.
3. Thursday, Jan. 21. Electrolysis. Electrolytic corrosion. Storage-batteries.
4. Thursday, Jan. 28. Electromagnetic induction. Theory of the dynamo.
5. Thursday, Feb. 4. Practical management of shunt motors.
6. Thursday, Feb. 11. Practical management of series motors.
7. Thursday, Feb. 18. Steam engines and steam turbines.
8. Thursday, Feb. 25. Underground conduit systems.
9. Thursday, March 4. Voltage regulation.
10. Thursday, March 11. Ohm's law applied to distribution problems. The three-wire system.
11. Thursday, March 18. Ohm's law applied to electrical measurements. Ammeter, voltmeter and galvanometer methods.
12. Thursday, March 25. The physics of light.
13. Thursday, April 1. Arcs and arc lamp mechanisms.
14. Thursday, April 8. Incandescent lamps.
15. Thursday, April 15. Principles of recording wattmeters.
16. Thursday, April 22. Elementary principles of alternating currents.
17. Thursday, April 29. Alternating currents continued.
18. Thursday, May 6. Transformers.
19. Thursday, May 13. Alternating current motors.
20. Thursday, May 20. Synchronous converters.

during a lecture from a horizontal to a vertical lantern, also a special projecting galvanometer having a transparent scale, which could be placed directly before the lantern. The galvanometer can also be used with shunts as an ammeter; with resistance, as a voltmeter; with a thermo couple attachment, it will indicate temperature; and with a speed tachometer it indicates speed, all of these being readable on the screen. For alternating-current work new forms of projecting wattmeters, ammeters and voltmeters have been built for the writer. With this combination it is possible to perform on the lecture table and screen, any experiment which can be performed in the laboratory. In two lectures, for instance, it is possible to perform all of the experiments of simple electrical measurements, given in 20 afternoon sessions in college, provided the constants be properly chosen. The writer, for instance, has projected a voltmeter reading on the screen and in 25 minutes gone through all of the calculations and with a standard cell and potentiometer calibrated the voltmeter directly before the men. This, however, is an extreme case, although the Wheatstone bridge, the Thomson double bridge, and similar apparatus are demonstrated.

In connection with the lecture course a syllabus is printed and distributed to the men, giving for each lecture an outline of the ground to be covered (see Table II.) This syllabus also gives directions for study so that auxiliary reading may be carried on from week to week. In addition to this, weekly bulletins are posted calling attention to the lectures. After the lecture the men are free to ask questions to come forward and examine the apparatus, or to make any suggestions in connection with the course. The lectures are given weekly, afternoon and evening, so as to afford all an equal opportunity to attend.

This work was started three years ago by the Brooklyn Edison Company, which has continued it each year since. Two seasons have now been given by the New York Edison Company and this year is the first season for the Boston Edison Company. This year the work was expanded by the New York Edison Company, who have been giving a course of laboratory work and a course of talks by various professors and designing engineers as well as the experimental lectures.

As this work has now been carried on for three years it seems proper to ask whether it has been a success and wherein have the various companies benefited. Increased loyalty of the men to the companies has been the first great benefit of this work. The personal interest of the managements has created in the men a very kindly spirit and a feeling of pride in the home company. The men have felt that the company has been endeavoring to raise their technical standard so that they could advance, and in time occupy positions which now have to be filled from outside talent. The question may be asked as to whether this work would not in time serve to make the men discontented, whether they would not feel that as they had attended all of the lectures for a season, that they should immediately be promoted to such an office, for instance, as general manager of the company. While it is true that a little knowledge is sometimes a dangerous thing, our results show that a little knowledge in this case has served more to whet the appetite of the individual, and make him realize his own limitations. The men have become more earnest, more inquiring, less mechanical, have read the technical papers more, have kept the librarian busy, have purchased many technical books and have kept themselves busy.

By having a better understanding of the work in which they are engaged, the men are better able to handle their apparatus,

TABLE II.

LECTURE NO. 5. FEBRUARY 4, 1909.

The Practical Management of Shunt Motors.

Preliminary.
Slide showing simple dynamo.
Slide showing windings of shunt motors.
Magnetic Circuits of Field of Shunt Motor.
Parts of enclosed motor.
Field winding has high resistance.
Armature winding has low resistance.
Resistance values determined with ammeter and voltmeter.
Way of connecting field winding to circuit.
Short-circuit current.
Polarity of field coils.
Change of direction of current through field coils causes change of polarity.
Way of determining whether or not field coils are properly connected.
Self-induction of field coils; danger of opening field circuit.
Magnetic Circuits of Armature of Shunt Motor.
Loop of wire and development of armature.
Magnetic circuits of armature.
Formed coils and spacing of same.
Various armature windings.
Change of polarity of armature circuit caused by changing direction of current flow.
Magnetic circuits of armature and field, cause of rotation.
Starting of a Shunt Motor.
Diagram of circuits.
Excitation of field coils.
Precautions to be observed to prevent opening of field circuit through body.
Connecting lamp board in series with armature, causes rotation when field coils are excited.
Use of starting box.
Starting current of motor shown on screen.
Function of overload release.
Function of magnet arm on starting box.
Changing Direction of Rotation.
Change of field terminals.
Change of armature terminals.
Change of both armature and field terminals.
Speed Variation.
How to connect in field rheostat. Value of its resistance.
How to tell whether resistance is " all in " or " all out."
Variation of speed, measurement of values, change of field curren .

How to tell from starting box when field current is open at starting.

Precautions against starting motor with all of the field resistance in circuit.

Theory of speed variation.

Location of Trouble.

Motor will not operate. Why?

Defect may make itself evident at first glance.

Bearings, clearance, brushes, broken terminals, etc.

Note:

With light fuse in circuit turn on starting box first few points and let it come back.

If it flashes, but machine does not rotate, field circuit may be O. K.

If starting box smokes or machine runs very fast, field circuit may be open.

When machine is operating, if commutator flashes as it goes round it may be a high bar, a short-circuited coil, or a hard spot in the brushes.

DIRECTIONS FOR STUDY.

See Swoope, pages 393 *to* 414 *inclusive.*

See Thompson's Elem. Lessons, pages 448 *to* 455 *inclusive.*

See Sheldon's, pages 185 *to* 207 *inclusive.*

a mistake in the use of which, due to lack of knowledge, might sometime result in damage far greater than the cost of a season's lecture course. The men have also been taught to appreciate the danger which is always present, and to use due caution at all times, particular points of danger being emphasized. As 90 per cent of the accidents which occur are due to negligence or lack of knowledge, it is realized how important it is that a man should have as thorough a knowledge as possible of the particular apparatus with which he has to deal.

The men have also been taught to think quickly, which is a valuable asset in times of emergency, especially in the lighting field where continuity of service and close voltage regulation are all important.

Considering the many adverse factors attendant upon work of this kind, its success has been phenomenal. The attendance at the lectures of the New York Edison Company last year totaled slightly under 6000 men. The Brooklyn Edison Company this year had an average attendance 60 per cent better than last year. Out of 13 evening lectures given so far this year, out of a course of 20 for the Boston Edison Company, the average attendance has been 166 men. A slight fee has been charged in Boston for the entire course, and by slightly increasing this fee another season it is hoped to make the course entirely self-supporting. In New York and Brooklyn the course this season has been free to all employees. In Boston the same method was considered but it would have been impossible to have accommodated in the lecture room all who would have attended. As it was, for the first six lectures the seating capacity was taxed to its utmost.

Franklin Phillips (by letter): Twenty years ago at least, a change was observable in the skill of mechanics working in the engineering trades. This change was slow at first, but has rapidly increased, owing to the passing away of the old-time mechanics who were trained by long apprenticeships to become skilled workmen. Their ranks were still further depleted through the promotion of these men from the bench and machine, to positions of foremen and managers of works, those having ability to handle men and the ambition to seek a higher paid position, thus being able to obtain the managerial prizes.

The advent of the handy men and the introduction of automatic machinery has led many manufacturing concerns to practically abandon the apprentice system. This has led to a constant diminution in the ranks of skilled workmen, until now the whole country has become sensible of its dependent position as a manufacturing nation and is looking about with its hands in the air crying for help. A service of three years with that able instructor Professor Sweet (and later a four years' apprenticeship, in the Whitworth School, followed by work at the establishment with which I am connected) may have prejudiced me too strongly in favor of the old-time apprenticeship, but I often recall the words of my good father when I had complained to him of the irksomeness of running a screw-cutting lathe or some equally dull operation, he had soothed me with the words—

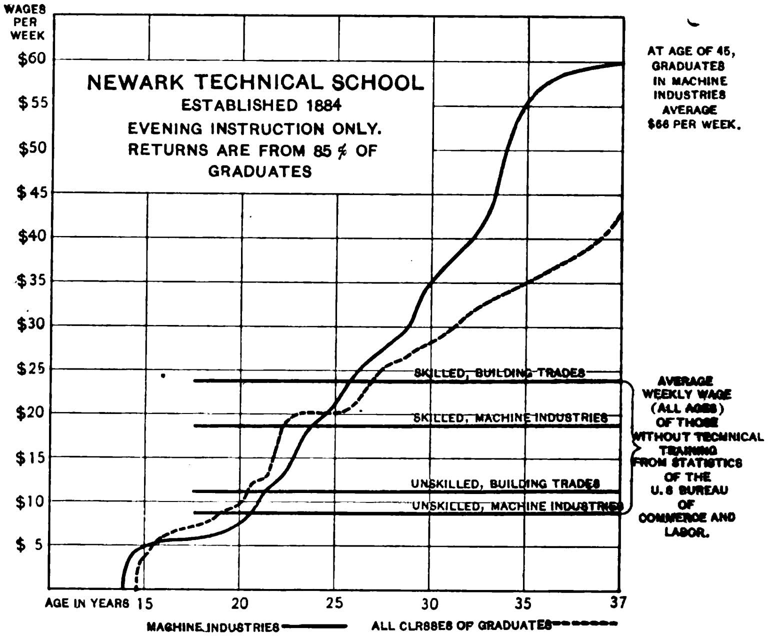

FIG. 1—The money value of industrial training.
Compiled by New Jersey Commission on Industrial Education.

" My son, you must remember that there is no royal road to knowledge ", and so I believe to this day, there is no short-cut method of making skilled mechanics.

Engineering establishments must get back to the old-time system of apprenticeship, and whether the trade unions like it or not, (they at present put limitations on the number of apprentices employed), sufficient numbers of apprentices must be installed to meet the needs of each particular establishment. This plan works out automatically, as but a limited number can be handled by any one establishment at a given time. The part-time system of Dean Schneider may have undoubted advantages in some localities and would seem to be particularly adapted to cities or towns where there are a number of industries producing nearly the same kind of an output, but may not be at all adapted where the industries are small or widely varied.

To my mind the manual training school does not touch the subject at all, and is as elemental as regards teaching a trade as the primary department is to the full college education, or the boy's kite flying as compared with the skilled operations of Wilbur Wright in his flying machine. I recognize the fact that something must be done towards the education of the youth, both girls and boys, of this country, who are between the ages of twelve and sixteen, those who leave the grammar schools or the early years of high school, and cannot go to work for legal reasons (in New Jersey) until sixteen years of age. These, therefore, must be educated, and preferably in some useful work.

My experience as a teacher in the old-fashioned practice and as an observer of the work of graduates from the establishment with which I am connected, who were also graduates of the Newark Technical School, leads me to believe that the most value and the quickest results can be obtained from the establishment of the technical night school. I refer the members of this society to the lately published report of the Commission on industrial education, State of New Jersey, to the chart shown in that publication [Fig. 1], and the printed matter of Appendix C. under the title of " The Money Value of Industrial Training." Professor Colton, dean of that faculty, shows that it costs but $42.00 per capita per year to educate the pupils, while the average wage of the graduates at the age of 45 has risen to $60.00 per week from a basis of $20.00 per week, the average wage of a skilledm echanic.

Do not think for a moment that in educating your apprentices you will increase the available stock of more highly educated machine hands or vise hands, for you will not see them again in this capacity, and this condition will prevail until the demand for foremen, superintendents and office engineers is met and the surplus, if any, for lack of employment must seek the old positions. My thought is, that the trades can be best taught in the engineering establishments, while the schools, either day or night, to my mind preferably the latter, for the time being, will teach the things requisite and not dwelt upon during the course of daily work.

John Price Jackson: The writer highly appreciates such experimental work in pedagogics as is being performed by Professor Schneider and some others in this country. He believes that much good is coming therefrom, and that certain pedagogic principles are being developed which have in the past lain more or less dormant. The writer, however, is not willing to support the tenets of Professor Schneider's faith in all particulars. It is a very grave question whether the average boy can to the best advantage take his college training week in and week out. Indeed, the number who can do this is probably so small as to make the system narrow in its application. Assuming that the college does run in part a basis of a few days in college, then a few days working for some industrial establishment and so on, it is readily seen that the teaching force and schedule arrangements of studies become difficult and expensive. It must further be noted that students who take their college work in this way, have, in a sense, two masters, and that they lose a large part of the most desirable element of college life which goes with class organization, active part in class and other collegiate student functions, and, to a certain extent, the effect of close personal contact which the college boy has with his fellows. It is recognized among college pedagogs that first of all the boy must daily do good, sound, hard, practical work, and it is also clearly understood that the associations of college life are in many ways useful in the development of the character of the man who is to be of the greatest value to his community.

I am inclined to favor the proposal of Mr. Fred Taylor of the American Society of Mechanical Engineers, who is now offering to take men immediately after the freshman year into his shops for a term of one year. Following this, he expects them to complete their course in college, going to his shops for the long vacation periods. He believes that in this way, he will not disturb the continuity of the college work, nor seriously handicap his shop organization, but that he will obtain the boy at a period of his training, when he is most susceptible to the proper industrial spirit. I agree fully with Mr. Taylor's view, but would prefer to have the boy spend the year in the shops between the junior and senior years in college, and after graduation spend another period in the shops, or other industrial establishment for further perfection and development of his practical ability.

Professor Schneider has insisted that it is impossible for a boy to gain good practical experience in college. To a certain extent, this may be true; but by employing men as teachers who have had successful engineering experience, by bringing in industrialists as professorial lecturers for a few weeks at a time; by having frequent individual lectures by men of prominent success in the industrial world, and by having the technical school of the university directly under the supervision of a committee of successful industrialists, it is undoubtedly possible to so arrange the teaching, and courses, and life of the student that he can be filled with a proper professional spirit and pride in his life's work, and gain a true measure of his own value and worth in practical usefulness. All of these measures are being tried to a certain extent in the college with which the writer is closely associated and are seemingly working to excellent ends.

The author's contention that men, who are by nature unfitted for the engineering professions, are too frequently graduated from technical courses, has some foundation. Nevertheless, if the men at the head of the technical schools use sufficient pains to inquire into the characteristics of their freshmen and sophomores, and to eliminate those unfitted, such criticism need not long continue.

One of the greatest lacks to-day in our technical courses is undoubtedly the absence of sufficient regularly scheduled training in shop or industrial systems, and in the handling of men. This criticism has come to the writer from managers, presidents, and many others prominent in forwarding industrial enterprises. To correct this weakness, the writer has prepared and introduced into the curricula of one college, a course which is intended to give an excellent foundation, and at the same time prepare along the more specific lines required by the manager or superintendent. The course is identical with the other engineering courses in the freshman and sophomore years, including in the latter year, industrial history. In the junior and senior years, in addition to the fundamental engineering subjects of applied mechanics, materials of construction, heat and heat engines, structures, design, shop practice, applied electricity, geology, etc., are given courses in modern language—5½ years, including entrance. Shop systems, shop economics, factory planning, contracts, principles of economy, labor problems, and logic. If the criticisms of employers of technical graduates are well founded, this course should perform an important and valuable function, and should mark a direction toward which colleges should aim.

Willard S. Atkinson: Industrial education, in my opinion, should begin in the schoolroom. I have seen many instances of men who gave every evidence of developing into the best of mechanics through shop training, come to a full stop in their development, on account of lack of knowledge of the fundamentals underlying their work, or lack of mental training which would enable them to acquire such knowledge for themselves. To my mind much of the time now devoted in our public schools to subjects of purely academic interest, or entirely useless ones, could with profit be assigned to the study of elementary physics, mathematics and chemistry, and, it goes without saying, mechanical drawing. The embryo mechanic or industrial worker, whatever be his field, will find that there will come a time, in the course of his development into a high-class worker in his field, when the knowledge thus attained of these subjects will seem to him the handiest tools he possesses. In this age of huge industrial enterprises and of immense and costly shop equipments, any attempt to duplicate the essentials of the aggregate of these must appear very meagre indeed. So why not devote all the time that can be made available to the boy, while he is at school, to a thorough knowledge of the underlying principles of the sciences on which the modern enterprises are based? Then when he leaves school and applies for a job, he at least has a foundation under him on which to build, and a mental training of the right kind that will help him to think. For in this age of automatic devices, and huge and intricate machinery, the industrial worker's value to his employer is becoming less and less dependent on his manual ability, and more and more on his knowledge of the work in hand and his ability to think.

DISCUSSION ON "THE PATENT SYSTEM IN ITS RELATION TO INDUSTRIAL DEVELOPMENT." NEW YORK, MAY 18, 1909

(Subject to final revision for the Transactions.)

President Ferguson: The subject chosen for to-night is one in which every member of the American Institute of Electrical Engineers is either directly or indirectly interested. We are especially fortunate in having among our members a man able to discuss this subject so authoritatively. He is a lawyer who stands foremost in his profession, having been general counsel to the largest electrical manufacturing company in this country for more than 20 years. He is able to treat the subject not only from the legal standpoint but from the standpoint of the business man and executive officer, as he was for six years the president of the largest electrical undertaking in this country representing an investment of over 500 millions of dollars, the American Bell Telephone Company.

Francis B. Crocker (by letter): This subject is one in which I am greatly interested. Ever since Charles G. Curtis and I jointly obtained a patent for a telephone call system in 1880, while students at Columbia, I have given much attention to inventions and patents, including the prosecution and defense of patent suits. The paper is particularly valuable because it sets forth the fundamental basis of patent rights, showing them to be well grounded, historically, legally, and morally. They have been recognized for more than 400 years and have had substantially the same legal status in England for nearly 300 years. Their moral justification is found in the fact that they " promote the progress of science and useful arts," in the words of the Constitution of the United States.

It is a common notion, especially among those who have not given the matter much attention, that the patent system is of doubtful benefit; some think it positively obnoxious. This notion probably arises from the fact that a patent being a monopoly, is classed with all other monopolies and shares their unpopularity. The patent right is really a just reward for service rendered to the community; it is also to encourage others to render like services. As stated in the paper, ever since the enactment of the " Statute of Monopolies " in 1623, all monopolies of the objectionable kind, granted for mere "buying, selling, making, working or using " of some already known article are illegal not only in Great Britain but also in the United States, which has adopted fairly closely the legal principles of the mother country. The broad and clear statement of patent rights contained in the paper will do much to put the matter in its true light in the minds of electrical engineers who are particularly affected by patents because of the novelty and rapid progress of their profession.

I agree fully with Mr. Fish that in the main our patent laws are good and that they have been intelligently and honestly administered. Of course mistakes are made, but these arise mostly from failure to understand the extremely difficult technical points. Even when cases have been decided against my interests, I have not doubted the probity of the patent office officials or of the federal judges. Considering the extreme complexity of many patent cases, it is indeed surprising that the decisions are generally right or substantially right.

Nevertheless, there are defects, one of the most serious of which is the fact that " the methods of taking testimony in patent causes are cumbersome and expensive," as stated in the paper. Mr. Fish suggests only a very general and far-away remedy when he says: "that an intelligent and well directed effort on the part of the patent bar and the courts could bring about a reform in this direction." While I believe that the better element of the patent bar would be willing to have such reform, nevertheless the volume of business would be reduced, and human nature as a whole could not be expected to put forth strenuous and concerted efforts in that direction. In order to initiate this movement specifically and promptly, I suggest that the Board of Directors be requested to appoint a committee to investigate and report upon what reforms are desirable and how they may best be brought about. On this committee there should be representatives of the patent bar, manufacturers and operating companies (who have to pay the bills), also engineers that do not act as patent experts as well as those that do. This would insure a breadth and balance of views most likely to bring about the best results. The Standards Committee of the Institute has always had a similar all-around representation, and 11 years' experience has proved that excellent work is done by apportioning it to those who understand it best. Under these conditions the various interests are safeguarded and the conclusions are respected.

This same committee could also consider and report upon the establishment of a single United States appellate court in patent cases, as well as reforms in the Patent Office, especially in obtaining prompt and competent examination of applications, simplication of interference and appeal proceedings, etc. The entire revenue of the Patent Office and the past accumulation should certainly be expended to benefit that branch of the public service. There is no reason why the Patent Office should be run at a profit while the Post Office shows an enormous deficit.

Personally I consider the great bulk and complication of expert testimony the worst of all these present evils. Frequently the record consists of many ponderous volumes which could be reduced to one of moderate size and contain just as much or more of the real facts. This bad practice is commonly laid to the dishonesty of expert witnesses. In some cases this charge may be true, nevertheless the bulk and irrelevancy of the testimony would not be much reduced if every expert were perfectly honest. It is *partisanship* which is largely responsible.

Every day we hear arguments on political or social questions which do not affect the disputants to the extent of a single cent, and yet they will wander from the point, fail to admit the other side of the question, however obvious, quibble and struggle to maintain their own proposition even after they are proved to be clearly in the wrong. If on the other hand a question is left to anyone to decide, he will usually consider it in a conscientious, judicial manner and give his best opinion, endeavoring to eliminate obscure or immaterial matter. If two experts were appointed by the court from among specialists of experience and standing, the facts could be brought out in less than one-quarter of the time and space now required to mix them up. Most of the points would be settled with little or no controversy. In case the two experts failed to agree on certain matters a third could be called in; even if his decision were wrong, the case would be so boiled down that the court and counsel could see the precise issue.

The need of this reform is particularly pressing for electrical cases, because judges and lawyers have the greatest difficulty in understanding the electrical technicalities involved. I think that the Institute is the body most interested in and qualified to lead in bringing about the reforms proposed.

Albert G. Davis (by letter): It is difficult to discuss Mr. Fish's paper. The points which he makes seem so self-evident, after he has made them, and the paper is so convincing and so exhaustive, that criticism is impossible. During the last two or three years there has been a tendency on the part of a certain class of inventors and persons interested in inventions to criticise our present patent system. No two of the critics seem to agree on any particular remedy, and many of them violently contradict each other, but they all are in general agreement that something ought to be changed. They seem particularly to be troubled by the idea that the patent situation is being handled by the patent lawyers, and to feel that this is all wrong. The law has been handled by lawyers, that is, by a special class of persons who have given their whole time and attention to the subject, ever since the Babylonians inscribed their judicial decrees and contracts on clay and baked them into bricks. It will probably continue to be so handled as long as engineering is handled by engineers, or as long as the art of healing is handled by physicians.

The patent lawyers of the country, or at least those of them whose standing is such that their views are worthy of consideration, are a unit in their desire to simplify the patent procedure wherever such simplification can be effected without risk of injustice to litigants, and to see that the meritorious inventor receives adequate protection and adequate reward. This desire is only natural, because the minute it ceases to exist, that minute the patent system will begin to decline, and the occupation of the patent lawyers will be gone.

A good lawyer is a man who is trained in the idea of justice. All his instincts are in favor of justice. A good patent lawyer knows the benefit that has accrued to this country from the patent system, and realizes that this benefit is due to our patent system being the best in the world. He knows that bold and far-seeing men, individuals as well as officers of corporations, are engaged in research and development that must cost hundreds of thousands or millions of dollars before any practical results can be brought forth. He knows that this would not be done and could not be done if it were not for the patent system.

The complexity of our present procedure and the delay and expense attendant on any thoroughly contested patent litigation are not the fault of the patent bar, nor are they the fault of the judges, nor, broadly speaking, are they the fault of the system. The truth is that the questions necessarily arising in an ordinary patent infringement suit are exceedingly complex, so that patent litigation is necessarily one of the most difficult and, therefore, one of the most expensive sorts of litigation in which a man can engage.

I think that most competent patent lawyers will agree that most of the discontent comes from patentees or patent owners who have failed to enforce rights because, as a matter of fact, they did not have any rights to enforce; that is to say, people who have not really made meritorious inventions, but merely thought they had. Any patent lawyer of experience will agree with me, I think, that a man who has a meritorious invention and will hold on to it until the art is ready for it, whether that man be a millionaire or a workman at two dollars a day, will receive his reward. He has a piece of property which is of value and which can be sold. He may be foolish enough to allow himself to be swindled out of it, just as he may allow himself to be swindled out of a piece of real-estate, but there are always plenty of manufacturing companies and individuals willing to put money into a meritorious patent if they can only be convinced that it is meritorious.

The present American patent system has been built up by a steady growth and development through a century and a quarter, keeping what is good and rejecting what is bad. As it stands to-day it is the result of the combined wisdom of generation after generation of able lawyers and learned and conscientious judges. It is a better system to-day than it was 50 years ago, and it will be a better system 50 years from now than it is to-day. Like any other product of the human mind it is capable of improvement and it will be improved, but the improvement will not be produced by any one radical change coming at one time, but rather by the same slow growth by which all real legal and other reforms are effected.

Arthur Von Briesen (by letter): [This communication is not original with Mr. Von Briesen; it is a memorial circulated by the Merchants Association of the City of New York.]

Hon. Secretary of State,
The Senators for New York,
The Chairman of the Committee on Patents of the Senate, and the House of Representatives.

This Memorial is respectfully presented to your Honorable Bodies by the undersigned members of the United States Bar largely practising in patent causes. The law recently enacted by the British Government has already injuriously affected the interests of American patentees and manufacturers and calls for action on the part of our Government. Retaliatory measures have been suggested. By Section 41 of the Payne Tariff Act it is proposed to retaliate by subjecting inventors who are not citizens of the United States, when they seek patents in this country, to the same rules and restrictions which prevail in their own countries. But it has been found that such a provision in our law would do violence to International Treaties, particularly the Treaty of 1883, Article 2, which provides that in this country the citizens or subjects of foreign countries who are members of the Treaty shall enjoy the same privileges regarding patents that are enjoyed by our own citizens. Hence the enactment of a law such as Section 41 of the Payne Tariff Bill would constitute a breach of a solemn treaty and it would otherwise create administrative, judicial and commercial difficulties of such magnitude that the provision in question is by us deemed impracticable. In other countries similar restrictions exist which are not found in our law, the result of which is that the citizens of such countries receive much more liberal treatment and greater rights in this country than our citizens do in theirs. We therefore respectfully petition your Honorable Bodies to take measures which will lead to a new International Conference at which the question arising from the enactment of the said law of Great Britain may be thoroughly discussed with the view of bringing about a complete understanding between the nations, and the entire elimination of all needless and harmful restrictions. In such a Convention the representatives of the United States Government should be instructed to lay stress upon the intolerable conditions created by the enactment of the British Law and by the presence of similar restrictions in the laws of other nations. The objectionable nature of such provisions has indeed led to the question whether it might not be best for the United States to withdraw from the International Treaty regarding the protection of industrial property by giving one year's notice as called for by the Treaty. Should we withdraw from such a treaty, we can then be in position to enact retaliatory measures. But why not press upon the representatives of other nations the importance and value of the simple American system, which grants a patentee protection for a certain number of years, without placing any restriction whatsoever upon him, requiring neither the payment of taxes from time to time, nor the enforced manufacture of patented devices, nor the enforced granting of licenses. The American system in its simplicity has worked the greatest benefit upon our people. An inventor very frequently is ahead of his time. When his patent is granted, it may be laughed at, and frequently is, and it has taken some of the most meritorious inventors as much as ten or twelve or even fourteen years after the grant of that patent, before the value of their mental creation became recognized. During all this time the energy of the inventor is at work towards pushing his creation to the front; no discouragement is placed in his path by any restriction created by law, and as a result the industrial development of this country has been greater than that of any other. Where heavy taxes are required to be paid from year to year,—and in many countries taxes increase from year to year,—inventors, unless they are very rich, are enforced to abandon their patents and relinquish that splendid energy which accompanies the unrestricted patentee throughout the life of the patent. It may well be said that thousands of patents which lapsed for non-payment of taxes in foreign countries would have proved of great value, had the inventors been permitted to continue their privileges to the full end of the original term.

Analogous obstacles are created by the laws that require patented devices to be manufactured in the country in which the patent is granted to a foreigner. The intercourse between nations has become so intimate and so thoroughly interlocked that provisions of this nature work more harm than good in stifling, for the imaginary benefit of the home country, the enterprise of intelligent inventors, who bring into play that splendid mental and intellectual competition which, where a patented machine comes from a foreign country and seeks to cover the market, induces the native inventor of higher grade to create organisms of greater importance and greater value than those that come from abroad.

That license restrictions should not be put upon patentees who under the Constitution are to be granted exclusive rights, is a point that has been thoroughly discussed in the case of *Continental Paper Bag Co. v. Eastern Paper Bag Co.*, decided by the Supreme Court of the United States in June, 1908, and reported in 210 U. S. Reports, page 405, where the court after showing the intent of our Constitution and the object of the law to enter into contractual relations with inventors uses the following language;

"The inventor is one who has discovered something of value. It is his absolute property. He may withhold a knowledge of it from the public and he may insist upon all the advantages and benefits which the statute promises to him who discloses to the public his invention." (p. 424); and then says:

" As to the suggestion that competitors were excluded from the use of the new patent, we answer that such exclusion may be said to have been of the very essence of the right conferred by the patent, as it is the privilege of any owner of property to use or not to use it, without question of motive." (p. 429) * * * " In some foreign countries the right granted to an inventor is affected by non-use. This policy, we must assume, Congress has not been ignorant of nor of its effects. It has nevertheless selected another policy. It has continued that policy through many years. We may assume that experience has demonstrated its wisdom and beneficial effect upon the arts and sciences."

Your petitioners therefore pray that measures be taken towards bringing about at the earliest possible date another International Conference regarding the questions touched upon in this memorial, with the view of bringing the laws of all civilized nations into more thorough uniformity so that no restrictions may be placed in the path of meritorious inventors who are citizens of other countries and who desire to have their inventions duly protected in this country.

Thomas B. Kerr: If the matter of taking testimony were left to me, I would decide it promptly and decisively. I would not permit my opponents to cross-examine my witnesses. That would relieve my clients of their objections. I have read Mr. Fish's paper several times and have got a new view of the patent law from it. I have been at patent law all my life, and have known no other practice. This has subjected me to this kind of criticism: One day I met Mr. Knox, the present Secretary of State at a club in Pittsburgh. We had a patent case together, and I had explained to him that we had to have an expert to testify as to certain scientific matters, and I had come to him for his opinion in regard to certain questions of law, collateral to the specific patent questions involved. He was discussing lawyers generally to some lawyers and laymen. He looked at me and said:

> There is one branch of the profession which should not be admitted to an equal standing with the others. I mean the patent lawyers. If it is a question of mechanics they must hire an expert; if it is a question of law they must hire a lawyer.

I told him that that was the first time I had ever heard defined the status of the patent lawyer and that as I understood society, the most important man to be found was the middle man. The function of the patent lawyer is between the law and science, between the engineers and the court, because the engineers talk in a language that the court does not understand. The patent lawyer must get an inkling of the inventor's meaning, and convey it in simpler language to the court. Judges have confided to me that their greatest difficulty in patent cases was in understanding the testimony of the experts.

I never fully appreciated the Constitution of the United States until I read Mr. Fish's paper. In recent years the only part of the Constitution that I have read more than two or three times, is that upon which the patent system is founded, but I never appreciated the wisdom of that provision until I read Mr. Fish's paper. What possible improvement could be made upon it from a practical standpoint? How can you pay for something with nothing more perfectly than the Constitution pays the price, or prescribes the price which the country shall pay for inventions. It gives to the inventor something the public does not own, and yet it is so perfect a provision that out of it not only does the inventor gain his reward, but the country gains the prosperity which Mr. Fish has spoken about. I agree with him that American progress in commercial, industrial, and scientific lines is largely due to that one provision of the Constitution.

Now what handicap or harm comes out of it? Does it prescribe or put any limiting conditions upon the inventor? Does it in any way dampen his ardor or ability? No! It simply clears the track and says, "Now, run your race." For an invention, properly patented, is but an opportunity given to man, and it is of no value to him unless he puts back of it the same industry, purpose, and judgment which is necessary to success in any other line of endeavor. The fathers that wrote that provision laid the foundation for the most splendid patent system ever devised.

Mr. Fish pleads for support of the patent system. I do too. It has its weaknesses, like every other human institution. But it is the best patent system extant. The engineers especially have an interest in it, because in the future nature, under stress of greater intelligence, boldness, and earnestness of investigation, will yield her secrets much more freely than in the past. There is open to all men the rewards which come to the successful inventor, but the patent system is needed to give him the opportunity to profit by his labor.

Livingston Gifford: I think that the sentiment of the bar is absolutely unanimous in favor of the patent law as it stands to-day. I say, unanimous in a general sense. As Mr. Fish says, every individual has some fault to find, something that he would suggest as an improvement, but everything suggested as an improvement by any individual is generally condemned by almost everybody else. So I think that taking the general sentiment of those that know, the conclusion is that the patent law as it stands is satisfactory.

On the other hand, the consensus of opinion is that the system of administration—the taking of testimony and hearing and deciding cases—is all wrong. It is antiquated and requires some changes to adapt it to present requirements. It has existed for probably three-quarters of a century, ever since the patent law commenced. It is worn out and does not meet present-day demands. It is complicated, cumbersome, and does not reach results. But when all this has been said, how is it to be made any better? We have practiced under it for over one-half a century, and everbody is condemning it all the time. Yet I have never heard a suggestion from anyone of any improvement that anybody else would agree to as being an improvement. As soon as an attempt is made to curtail the system, one runs into difficulties just as great in other directions.

It is very easy, and the common practice of everybody under all circumstances, to say, " have a committee appointed ". But Mr. Crocker does not suggest any change for a committee to consider. It would be useless to appoint a committee and expect them to revise a system which has existed for three-quarters of a century, without suggesting in advance any scheme of improvement.

It seems to me the proper thing is to follow the suggestion of Mr. Fish; that is, to have a court that takes and hears all patent cases as a court of last resort, so that the court can become acquainted with all of the difficulties that arise. That court, perhaps coöperating with all interest in patents, may work out a solution of the problem and cure the evil in the long run. I see no other possible way of accomplishing it.

E. W. Rice, Jr.: Mr. Fish speaks of the work of the inventor as that controlling the forces of nature and teaching man how to apply those forces to shaping and transforming the raw materials that are available for his use, as distinguished from intellectual, moral, social, and imaginative development.

I have no doubt Mr. Fish will agree with me that one of the chief characteristics of the inventor is his imaginative quality: I do not think a man can invent anything of value who has not the imaginative quality developed in very definite manner.

Mr. Fish's statement

> It has not been much of a disadvantage to the patent system or to patentees that the judges have, as a rule, had no special technical training.

is of great interest to me, for at one time, I thought it was a very great disadvantage not to have had this training. I still think it would be desirable in an appellate court, such as Mr. Fish has suggested, for one of the members to have a first class engineering training. Nevertheless, my experience with lawyers and patent lawyers has astonished me. They show such wonderful capacity in grasping abtruse engineering problems, and in restating them in such a clear and simple manner that the so-called expert is often confused. I think, therefore, that even without an engineering expert sitting as a member of the court, the system is fairly safe. That has often happened in my experience.

It is self-evident that one of the great advantages of our patent system is the stimulation of invention. Mr. Fish has referred to the rewards of inventors. It is a most difficult subject, one with which I have had to deal personally, and on many occasions I think we would all like to see inventors reap the richest rewards of their efforts. However, I believe that inventors, as a class, do receive a full measure of reward, compared with similar efforts in other lines. It happens under our patent system that a monopoly is given only for a certain kind of ideas. Now there are other ideas and efforts just as important and valuable which are not patentable. The manager of a works or the executive of a business must use great originality and great skill in managing the business, but he has no means of obtaining a monopoly on his ideas or methods.

It is also true in many cases that inventions, as Mr. Fish states are only valuable as incidents to the manufacture, and cannot be segregated and appraised separately. It often happens that an inventor makes an invention which he believes will save his employer a large sum of money, and he feels that he ought to be rewarded accordingly. But the difficulty has been accurately to determine the saving in the particular case. Others have contributed to make that invention possible, and others must help to make it profitable; and it is impossible to segregate and value the individual contribution.

As to the improvements of the patent system, I think it would be difficult to offer any suggestion beyond the one Mr. Fish has made as to a single court. We all agree, I think, that it would be a great improvement if some method could be devised to limit cross-examination. I have felt very keenly at times that my time has been wasted by opposing counsel. I think all engineers and inventors brought into patent cases, who are not patent experts, regard the waste of time given to the taking of direct and indirect testimony, as something almost unbearable. They would rather be engaged in the work of designing or inventing new apparatus. Therefore, any suggestion which will improve the practice in that respect will be welcomed.

Chas. P. Steinmetz: After the very comprehensive paper of Mr. F. P. Fish, I cannot see how I can add anything, still less criticize the paper; but shall merely discuss one particular feature of the patent situation from my point of view as an inventor. I have made a few inventions myself. The direct financial gain which I have received from inventions amounts to $500. Indirectly, in salary and reputation, however, I believe I have received at least the value of my inventions; so that I can find no fault in my personal experience, and my treatment as an inventor. Still, I recognize that considerable fault is found with the operation of the patent laws, by inventors and others.

In criticizing the operation of our patent laws, I believe it very important to realize the point of view from which the criticism is made; because what may appear as severe criticism from the manufacturer's point of view, may be desirable and necessary from the inventor's point of view; and inversely.

To illustrate: The requirement that the invention should be manufactured within a short time limit, of one year or two years would offer very little handicap to the manufacturer who can arrange to have somebody put to work on it; but it would be fatal to the inventor, as it would practically deprive him of the chances of reward, since most inventors are not able to carry out the manufacture of their inventions on their own capital. Therefore, if this were a legal requirement, the inventor would have to turn over his invention to a manufacturer at any price, or lose it altogether. So, you see, we may criticize from one point of view a feature which is entirely justified from another point of view; for you can realize that the manufacturer may desire to have such a clause, as it would turn the inventor over to him, helpless, while the inventor should for the same reason strongly oppose it.

I propose to discuss this paper from the standpoint of the inventor, and not that of the manufacturer or the capitalist; because I believe the inventor who has created something which did not exist is the one to be rewarded, and to reap the benefit, while the capitalist, who makes the exploitation of the invention possible, by financing the business, or the manufacturer, are entitled to interest on their investment, to the return of the money they put out, and an additional return appropriate to the risk of the investment.

Developing an invention is not a safe investment like putting money into real estate, but is rather a gamble; and, therefore, the returns of capital should be very much higher to compensate for the risk involved. We do not realize the risk of investment in an invention because it is human nature only to see success, and forget failure. For instance, we consider the success of the Bell telephone, but we forget the Keeley motor. At the present time, everybody knows that the Bell telephone was a great invention, and the Keeley motor a humbug, yet in the view of the technical adviser, at the outset both appeared as wild fancies and capital could in neither case get reliable technical advice. So we must consider the time when capital was approached, and not the viewpoint of the historian whose judgment is guided by experience. Five years ago certain inventions in aeronautical matters would have been ridiculed. Nobody would dare to do that to-day, after the recent success in that field.

My opinion is that the patent laws should be drawn and executed in such matter as to give the greatest benefit and reward to the inventor. The ways of exploiting an invention by an inventor are three-fold. 1. The inventor may proceed to develop the invention for commercial use with his own capital; 2. He may interest capital in his invention; in short form an exploitation company. 3. The inventor may turn over the exploitation and development of his invention to an existing manufacturing company engaged in similar work.

As to the first point, the development and exploitation of the invention by the inventor at present, in the field of electrical engineering, the cost of development up to commercial exploitation of most inventions is so high, as to be far beyond the means of most inventors; and therefore, this is not feasible. Furthermore, the inventor is frequently not a good designer, and usually an inferior business man and administrator; therefore the chances are against his handling his own business satisfactorily. Besides, this method is not economical, as it deflects the time of the inventor from further creative work. Therefore, this method is feasible only in such rare instances, that it hardly needs to be considered. The second method: to interest capital in the development of the invention, the invention must represent a tangible value; it is the market value of the commodity on which depends the attraction to capital. This depends on how far the invention can control the industry or part of the industry to which it is related, and how safe the control is; that is, how good the chances are that the patent may be sustained finally by the court. Even with this assured, it still is an uncertain value, because it may never develop, but unforeseen difficulties may kill it, or just as it begins to develop and became profitable, somebody may invent something similar to it, which the courts consider as non-infringing. Or, again, when the commercial exploitation is ready, some other inventor may do the same thing, in a simpler and better manner and destroy the former invention just when it was about to start on a paying basis. The inventor needs the capital to develop his invention. The capitalist does not need the inventor. The stronger of the two parties is the capitalist; and therefore the control must lie with the capitalist and not with the inventor. It is not a question of morals, but the result of an economic condition, which in this case operates against the inventor. Very much more favorable is the situation of the inventor with regard to an established manufacturing company in similar lines, because in this direction the inventor has more the upper hand. He can hold back the invention until it is needed by the manufacturer, and the manufacturer has to come to terms, or as is more commonly the case, until the manufacturer realizes that this invention offers a certain financial advantage in his field, and therefore is willing to share the advantage with the inventor. As in this case, the conditions are more favorable to the inventor, it is the usual method of exploiting an invention.

The value of an invention, that is the reward which the inventor can expect, depends on its market value as a commodity. The market value depends on the control which the invention offers to the industry or branch of an industry, and the certainty of this control. That is, it depends on the broadness of the patent covering the invention, and the probability or certainty of the courts sustaining this patent. This is the feature which the inventor very often does not realize. He may in some individual cases be handicapped by broad inventions of others, from exploiting his detailed invention, and be led to the idea that broad patents are objectionable. But he does not realize that any limitation of the patent is an advantage to the exploiter of the invention, but not to the inventor. For instance, an engineer may get the conception, and make the invention that by combining several alternating currents, acting in different directions at different times, he can get rotation; and thereby transmit power. The patent of such a conception may by broadly covering the production and transmission of power by the combined action of several alternating currents, displaced in phase and position, or it may be limited to the construction of the particular motor, having two sets of field poles energized by two alternating currents displaced in phase. In the broader case, it would cover the use of two- or three-phase, secondary short-circuited member or energized by direct current, separate polyphase currents or currents derived by splitting the phase of a single current, or many other combinations which the inventor did not or could not think of, because the one who conceived the general idea, cannot think of all the particular applications to which it can be put. Such a broad patent would have a value assuring the inventor an adequate compensation of his broad idea. If, however, the patent is limited to a specific application which the inventor carried out, it makes the patent worthless, and deprives the inventor who had the broad and fundamental conception of the value of his work, because the first conception must necessarily be the crudest, the least refined, and least efficient, and any further development or modification thereof, after the general method has been shown, would, naturally, usually constitute a better way of doing it; and if the inventor is barred from the control of these lesser improvements, the fruit of his work and the results would accrue to those who had improved in detail on his particular principle. That would not be fair, and would be very harmful to the value of an invention, because it would make it possible to reap the benefit of a fundamental invention by someone who had simply made a modification or shown another way of doing it, of which the original inventor did not happen to think.

That is why I say the broadness of the invention is one of the most essential things from the point of view of the benefit of the inventor. Not so much from the point of view of the manufacturer, however, for the manufacturer may find it more convenient to limit it, for then he would not have to come to terms with the inventor of the fundamental idea. So the advantages are different from different points of view.

When the invention is finally adjudged by the court, the ownership of the invention has usually left the original inventor, and we are very liable then to imagine that it is of no moment to the inventor, as he has no further financial gain in the question of whether the invention is sustained or destroyed by the court. We do not realize that the destruction of a patent by the courts reduces the market value of all other inventions just as much, and any patent broadly sustained increases the market value of all inventions, and it is of special advantage to the inventor to have the value sustained, even though there is no direct financial gain from that particular patent. The failure to maintain a patent in court means the destruction or depreciation in value of all inventions, and that is the most serious blow to the inventor. To the large manufacturer in the industrial field it is rather immaterial. The destruction of fundamental patents, may destroy his monopoly of certain fields, but at the same time it would relieve him of the necessity of buying the control of an invention, and thus it would merely mean for the large manufacturer a readjustment of business methods, but would be neither a gain nor a loss. Many branches of business are monopolistic without being protected by a patent. Many are held as a monopoly where the patents expired years ago, and still the production of that commodity is carried out almost exclusively by the same manufacturers as before. Business methods, and not patent rights, give their control. To the inventor the destruction of a patent can only be a disadvantage. This is one of the most dangerous features. It is fortunate that the courts in general have been rather inclined to sustain patents. There is a great handicap in that direction, however, because electrical engineering has progressed enormously, so that what was a great invention ten years ago, is so self-evident to-day, that we do not realize how much of an invention it once was. One of the greatest difficulties after the lapse of many years is to imagine one's self back to the time when inventions were made; when what was a great invention has become common knowledge to every school boy, and we find the invention expressed in the terminology of the bygone days, when it commonly was impossible to describe ideas in the exact terms of to-day, as these terms did not yet exist in the language.

That is what you engineers and inventors must guard against. It is to our advantage, and nobody else's, to have the patent law allow us to make the claims of every invention sufficiently broad to cover all modifications of our fundamental idea which may be made, and to have the patents broadly sustained by the courts, because these two features constitute the market value of our work, and we are the only ones benefiting by it.

A paper presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y. June 29, 1909.

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LOSSES, INDUCED VOLTS AND AMPERES IN ARMOR AND LEAD COVER OF CABLES

BY H. W. FISHER

Part I of this paper is supplementary to the paper by Professor Whitehead, because the data presented were obtained from measurements made on the same cables prior to Professor Whitehead's tests. The results given cover conditions mostly not considered by Professor Whitehead. Any differences in impedance and losses presented are undoubtedly due to the coiling and uncoiling and shipment of cables, as this would tend to change the relative air-gaps between the armor wires. Slight differences may also have been caused by small differences in the lengths of the cables tested, or by differences in temperature.

Professor Whitehead shows clearly how the maximum possible inductance of armored cables can be calculated. His comparison between the calculated and measured impedances is extremely interesting and instructive. It is evident that the impedances of iron-armored, single-conductor cables cannot be calculated with any degree of certainty, because slight differences in the air-gaps between the armor wires materially affect the inductances of the cable. Moreover the induced volts and amperes are also affected by the same cause, hence the results given here for the iron-armored, single-conductor cable must be considered only approximate in their general application to iron-armored cables.

The first cable considered will be the first one mentioned in Professor Whitehead's paper; namely, single conductor No. 0 B. & S. G., insulated with $\frac{8}{32}$ in. paper over which is $\frac{1}{8}$ in. of lead with the usual jute bedding and No. 10 B. W. G. steel wires. The dimensions are as follows:

Diameter over copper strand, = 373 mils.
Diameter over paper insulation, = 873 mils.
Diameter over lead sheath, = 1123 mils.
Outside diameter, approximate, = 1500 mils.
Resistance of conductor per 2000 ft. = 0.21
Resistance of lead sheath per 2000 ft. = 0.53
Resistance of armor per 2000 ft. = 0.35

The following symbols are used to designate the different curves shown in Figs. 1 and 2:

A indicates that the distance between centers of cables was 1.5 in.
B " " " " " " " " " 9 in.
C " " " " " " " " " 24 in.

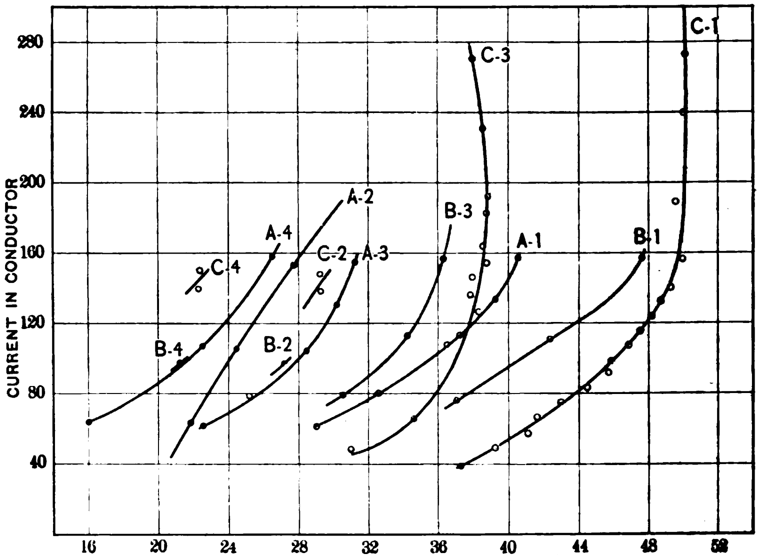

FIG. 1.

The figures used in connection with the above letters indicate the following:

1. Induced current or volts in lead.
2. Induced current or volts in lead, the armor being short-circuited at each end of the cable.
3. Induced current or volts in armor,
4. Induced current or volts in armor, the lead being short-circuited at each end of the cable.
5. Induced current in armor and lead, connected in parallel.

Fig. 1 gives the volts induced per 100 amperes in 2000 ft. of circuit. The reason for expressing the volts in terms of 100 amperes in the conductor is to give at sight a general idea of what pressure might be expected with a current somewhat near that used in practice. It will be seen that the induced volts are

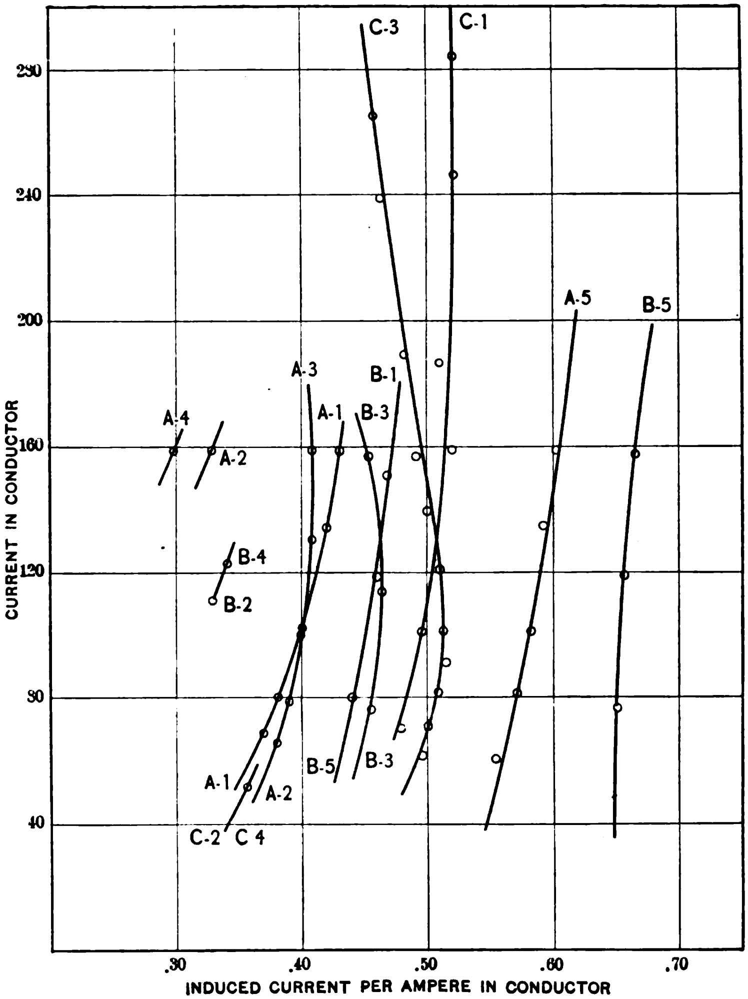

FIG. 2.

greatest when the conductors are farthest apart and when the armor is not short-circuited. Under these conditions, with a normal load of about 170 amperes the induced volts for 2000 ft. of circuit would be about 85. For the same load, a minimum in-

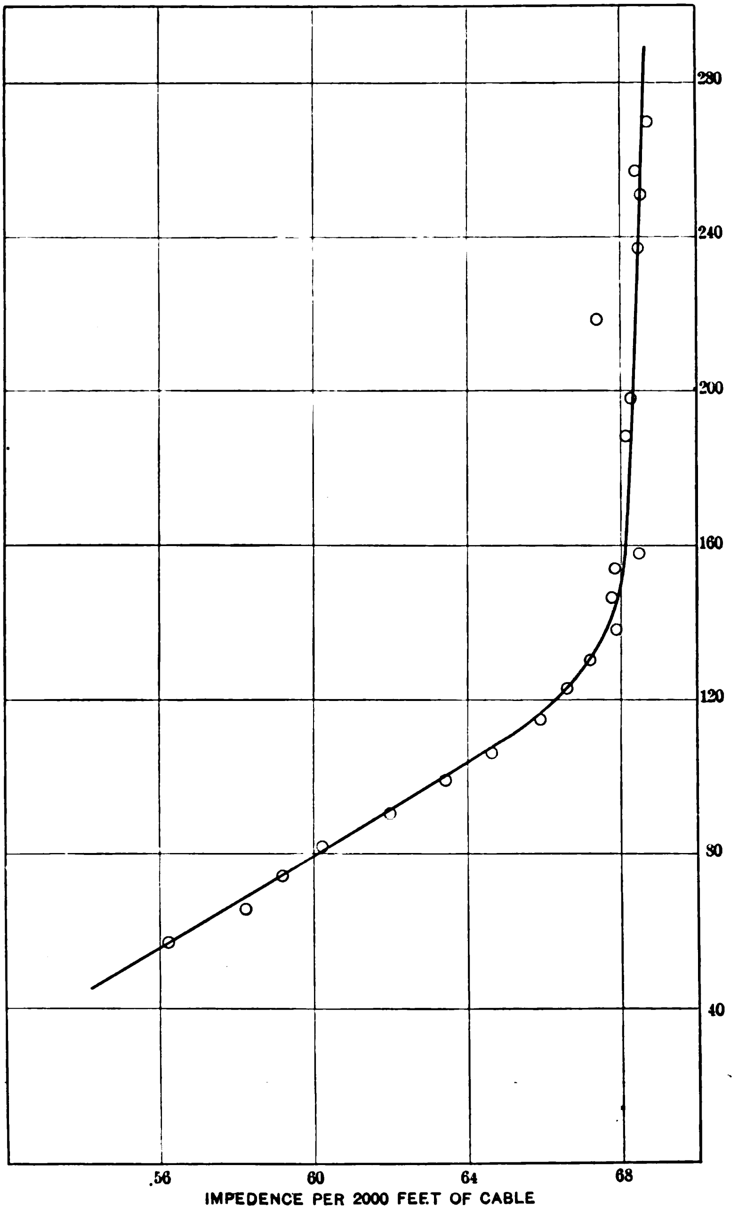

FIG. 3.—Current in conductor

duced electromotive force of 40 volts was obtained on the armor when the lead covers were connected at both ends of the cable. Between these extremes will be found various curves giving the different induced volts corresponding to the various tests that were made. The bends in the curves are characteristic of all circuits containing iron.

Fig. 2 gives the current induced per ampere in conductor. Here, as would be expected, the greatest current is obtained when both the lead and armor are in parallel. This current amounts to approximately 65 per cent of the current flowing in the conductor. From this it will readily be seen that an armored cable has a tendency to become warmer than an unarmored cable. However, in practice such cables are generally laid in water or in the ground, where the dissipation of heat is readily taken care of.

TABLE I.

Current in conductor	Effective resistance per 2000 ft. of circuit			
	No. 1	No. 2	No. 3	No. 4
60	0.33	0.36	0.36	0.35
100	0.41	0.41	0.40	0.37
160	0.46	0.45	0.44	0.40
240	——	0.48	0.48	0.42

Curve *C*-3 shows that a maximum per cent of induced current is reached with about 100 amperes in the conductor.

Fig. 3 shows how the impedance of the cable is affected by the amount of current. The knee of the curve commences at about 120 amperes; if sufficient current were applied, undoubtedly the impedance would begin to decrease. This will be shown in some curves given later.

Table I gives the effective resistance per 2000 ft. of circuit. The values given were obtained from wattmeter tests made when the cables were 24 in. apart. No. 1 indicates that neither lead nor armor circuit was connected; No. 2 that the lead circuit was connected at each end of the cable; No. 3 that the armor circuit was connected at each end of the cable; No. 4 that both circuits were connected. The conductor resistance to direct current was 0.21 ohms, so it will be seen that the maximum total loss is somewhat greater than double the conductor loss. When the distance between centers was 1.5 in. the losses in the No. 1

column were increased by about 1 per cent. In the Nos. 2, 3, and 4 columns, the losses were less as the distances were decreased. At 1.5 in. separation and with 60 amperes in the conductor, the difference was slight. With 160 amperes the decrease was about 5 per cent.

It will also be seen that the relative losses given in column 1 increase with the amount of current. For any particular current the losses in the several columns are not materially different, but this condition would not necessarily always be the case.

Single-conductor, copper-armored cable. This cable was made up substantially in the same manner as the first mentioned cable, except that the armor consisted of 24 No. 8 B. & S. G., hard-drawn copper wires.

Table II gives the volts induced in 2000 ft. of circuit per 100 amperes. Comparing this table with the curves in Fig. 1 shows a marked diminution in induced volts.

TABLE II.

VOLTS INDUCED IN 2000 FT. OF CIRCUIT PER 100 AMPERES

Distance between centers	Measured induced volts	
	In lead circuit	In armor circuit
3 in.	8.2	6.6
6 in.	11	9.5
12 in.	14.3	12.6
18 in.	16.2	14.5

Table III gives the current induced per 100 amperes in conductor. These tables do not call for comment, except that the induced voltage and current are proportional to the current in the conductor.

TABLE III.

CURRENT INDUCED PER 100 AMPERES IN CONDUCTOR

Distance between centers	Measured induced current	
	In lead circuit	In armor circuit
3 in.	14	44
6 in.	18	56
12 in.	23	63
18 in.	25	67

Table IV gives the impedance per 2000 ft. of cable for different distances with different connections of armor and lead. The calculated values are also given. In making these calculations it was necessary to estimate the resistance of the lead and armor circuits. The calculated values in the table are not so close as they would have been had the resistance referred to been accurately measured. The formulas for making these calculations were worked out after the cables had been discarded. The most interesting part of this table is that the impedance is greater when the lead circuit is connected at both ends of the cable than when the lead covers are not connected. This seems so contrary to what would be expected that I asked my chief assistant, Mr. R. W. Atkinson, to investigate the subject mathematically. In Part III of this paper will be found his graphical and mathematical solution of this problem; this solution shows the conditions under which the impedance of the cable may be greater when the lead covers are short-circuited.

TABLE IV
IMPEDANCE PER 2000 FT. OF CABLE

Distance between centers	Measured impedance				Calculated impedance	
	Lead and armor free	Leads connected	Armor connected	Both connected	Lead connected	Armor connected
1.5 in.	——	——	——	——	0.234	0.239
3 in.	0.245	0.255	0.252	0.253	0.262	0.262
6 in.	0.264	0.277	0.264	0.262	0.290	0.276
12 in.	0.288	0.304	0.273	0.271	0.321	0.284
18 in.	0.298	0.319	0.276	0.273	0.339	0.283

Part II.

This part deals with tests made on 100-ft. of steel-tape-armored cable of the following construction:

Size of conductor	No. 0 B. & S. G.
Thickness of paper	$\frac{8}{32}$ in.
Thickness of lead	$\frac{1}{8}$ in.
Diameter over lead	$1\frac{1}{8}$ in.
Diameter over armor	$1\frac{5}{8}$ in.
Dimensions of steel tape	0.039 in by 1.5 in.

Two such tapes were applied in same direction, overlapping each other.

Resistance of conductor.............0.0103 ohm.
Resistance of lead sheath............0.0300 “
Resistance of armor ....0.150 “

To designate the different curves, the following letters and figures were employed.

A indicates that the cables were 1⅞ in. between centers.
C indicates that the cables were 24 in. “ “
1 indicates induced current or volts in lead.
2 indicates induced current or volts in lead, the armor being short-circuited at each end of the cable.
3 indicates induced current or volts in armor,
4 indicates induced current or volts in armor, the lead being short-circuited at each end of the cable.
5 indicates induced current in armor and lead connected in parallel.
6 indicates lead or armor of each cable not connected nor inter-connected.
7 indicates lead short-circuited at each end of the cable, armor free.
8 indicates armor short-circuited at each end of the cable, lead free.
9 indicates lead and armor short-circuited at each end of the cable.

On account of the continuity of the steel armor, which forms almost a closed magnetic circuit, the curves for this cable are radically different from those of the steel-wire-armored cables.

On referring to Fig. 4, which gives the impedance per 2000 ft. at 60 cycles, it will be seen that the impedances are greatest when the armor and lead are not connected. and that a sharply defined maximum is reached with a conductor current of about 80 amperes. There is not much difference in curves A_6 and C_6 except at low current densities, where the greater distance between cables of test C_6 makes the air effect larger proportionally, and hence causes a greater difference of impedance between the two curves.

Short-circuiting the armor at each end of the cable (See A_8 and C_8) decreases the impedance only slightly. However, when both lead and armor are short-circuited (See A_9 and C_9) the impedance is very much reduced and only varies slightly with the amount of current in the conductor. In this kind of cable when the lead and armor are disconnected, the impedance may be 13 times the ohmic resistance. When the lead and armor are short-circuited, which is generally the case in practice, the impedance may be about 3.5 times the ohmic resistance. With larger conductor cables these ratios may be very much increased.

Fig. 5 gives the equivalent resistance per 2000 ft. of circuit. Here a current of about 60 amperes in the conductor seems to produce the maximum resistance. This resistance seems to be virtually independent of the distance between the centers of the cables. It is also striking that curves C_6 and A_6 cross curves C_9 and A_9 at points corresponding to about 40 and 200 amperes respectively, so that for small current densities and very large current densities the equivalent resistance per 2000 ft. of circuit may be less when the lead and armor are not connected than when they are connected. The maximum equivalent resistance is about 8 times the ohmic resistance when the lead and armor are disconnected. Under practical conditions of operation the equivalent resistance would be about 3.5 times the ohmic resistance.

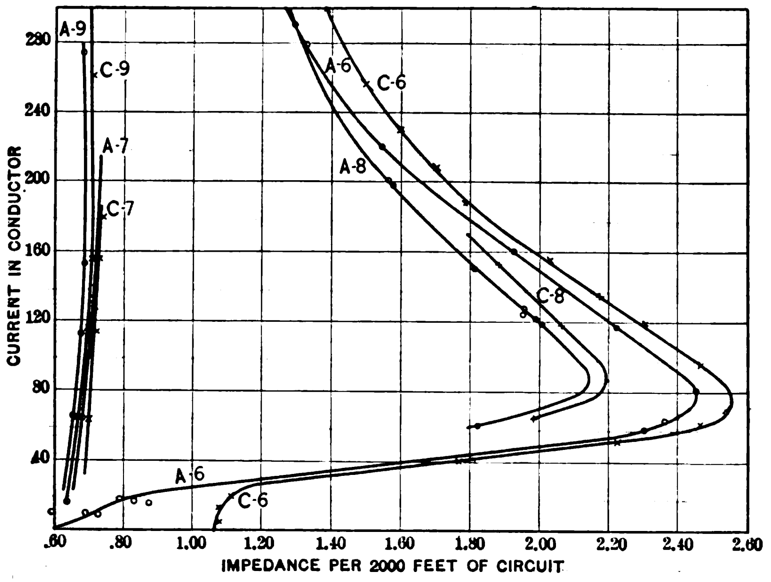

Fig. 4.

All this tends to show how advisable it is to use multiple-conductor cables all under one armor instead of single-conductor armored cables. The equivalent resistances given in Fig. 5 were found by means of wattmeter tests.

Fig. 6 gives the volts induced per 100 amperes in 2000 ft. of circuit. These curves show clearly a maximum rate of induced voltage that corresponds to about 80 amperes in the conductor. As might be expected, the induced voltage is greatest when the cables are farthest apart. At the maximum point the volts per 100 amperes are about 240, or actually about 190 volts. With a load of 170 amperes, the induced volts would be about 290. When the lead is short-circuited the electromotive force on the armor as given by C_4 is very small. The intermediate curves are in the order that one would expect.

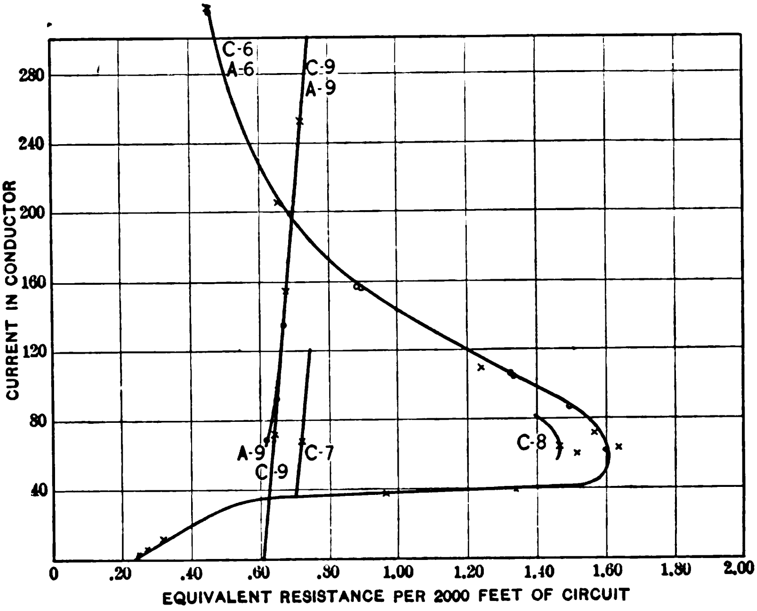

FIG. 5.

The significant fact brought out by these tests is that it is necessary to bond the armor and lead of single-conductor cables like the above, or else arcs may occur betwen the cables, or alternating-current electrolysis may tend to destroy the armor or lead. Even when such cables are laid in water, it would be best to bond the armor and lead occasionally.

Fig. 7 gives the induced current per ampere in conductor. With high current densities the induced current amounts to nearly 85 per cent of the total current. On account of the high resistance of the armor, the current induced therein is small

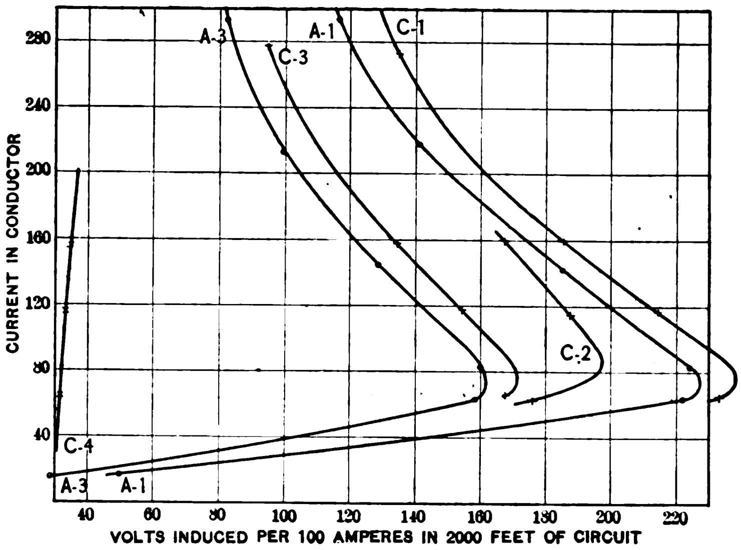
CURRENT IN CONDUCTOR
280
240
200
160
120
80
40
A-3
A-1
C-1
C-3
C-2
C-4
A-3
A-1
40
60
80
100
120
140
160
180
200
220
VOLTS INDUCED PER 100 AMPERES IN 2000 FEET OF CIRCUIT

FIG. 6.

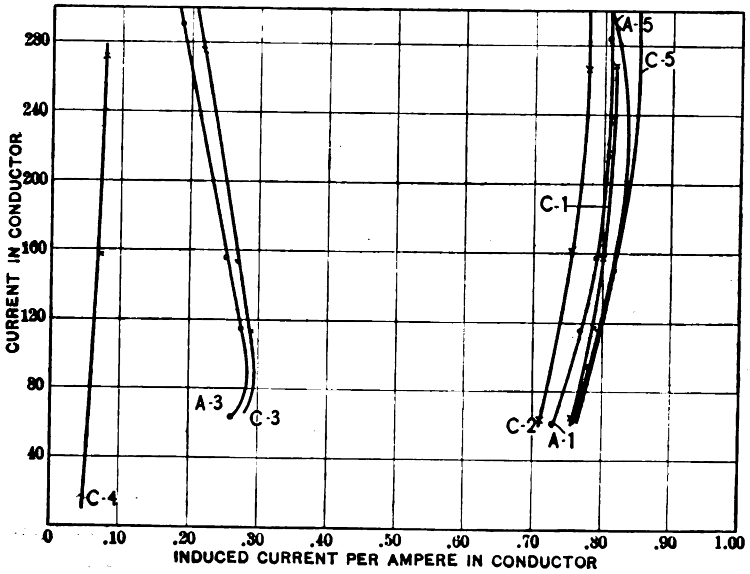
CURRENT IN CONDUCTOR
280
240
200
160
120
80
40
A-5
C-5
C-1
A-3
C-3
C-2
A-1
C-4
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
INDUCED CURRENT PER AMPERE IN CONDUCTOR

FIG. 7.

(See A_3, C_3 and C_4). The other curves are practically close together, and the greatest current is obtained when the cables are operating under practical working conditions with the lead and armor connected.

The large amount of induced current will not only increase the losses under operating conditions of such a cable, but will also, of course, tend to reduce the safe carrying capacity. Therefore, as previously stated, when armored cables have to be employed for alternating currents, all circuits should be placed in one cable. Where it is impossible to do this, the cables will be operated at an increased loss.

A comparison between measured and calculated data is found in Table V. This comparison will be of interest as an illustration of the accuracy of the practical method given at the close of the paper.

TABLE V

Current in conductor	Impedance		Volts induced on lead		Effective resistance		Induced current in lead in per cent of conductor current	
	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated
300	0.73	0.716	128	126		0.68	0.815	0.83
156	0.72	0.73	187	187		0.716	0.80	0.87
70	—	—	—	—	0.72	—	—	—

In Table V, the impedances and effective resistances are for lead covers short-circuited at each end of the cable. The values given in Table V are per 2000 ft. of circuit. Only one test was made of effective resistance and that with 70 amperes in the conductor.

In order to see if the correction method would give a closer agreement to the measured impedance than the method which is correct for cables without iron armor, the following calculations were made with reference to the steel-wire-armored cable mentioned in Part I. The distance between centers of cables was 1.5 in.

Measured impedance = 0.233
Calculated impedance by correction method = 0.226
Calculated impedance by theoretical method for cables without armor = 0.283
Current in conductor = 140 amperes.

The close agreement of the first and second impedances given shows that the correction method should be used in connection with armored cables.

Comparison calculations between the two methods as applied to the steel-tape-armored cable show a fairly close agreement. This agreement is no doubt due to the fact that the reactance of this cable is so great that the current induced in the lead forms a large part of the conductor current, and a large change in the reactance will only slightly affect the lead current.

PART III.

Calculation of impedance, etc. A graphical method may be used for determining the conditions existing when the armor or lead circuit is completed. The conditions required to be known are the reactance and resistance of the conductor and of the secondary circuit. These may have been measured or calculated.

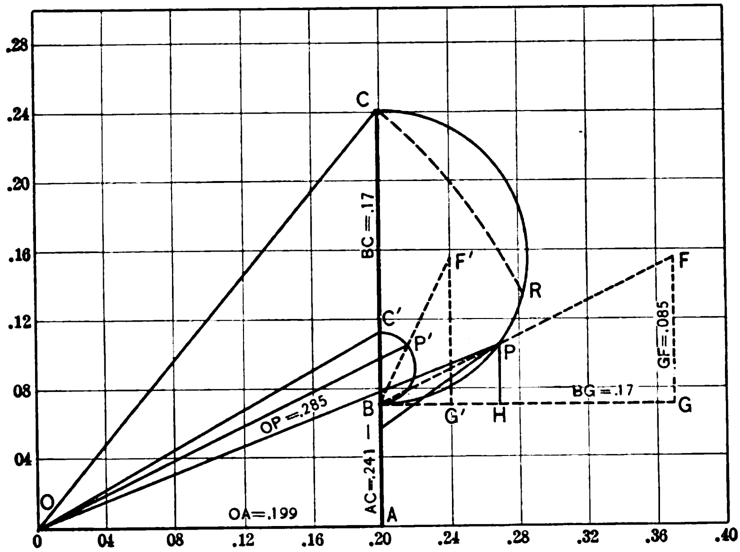

FIG. 8.

Refer to Fig. 8. The following construction has been made. OA is parallel to the X axis and is equal to the conductor resistance. AC is parallel to the Y axis and is equal to the conductor reactance. This may be culculated by formulas 11 and 14. BC is equal to the reactance of the secondary circuit and can be determined by formulas 12 and 14. The circle CPB has been drawn on CB as a diameter. BG has been drawn equal to BC, the reactance of the secondary circuit, and GF equal to r, the resistance of same. BF cuts the circle CPB at the point P.

Then OP is the impedance of the conductor when the secondary circuit is closed, OC being the impedance when this circuit is open. As r is varied, the locus of the point P is on the semicircle CPB; and it may readily be seen that the impedance may be greater with the sheath connected than when it is open. The effective resistance is $OA + BH$, the effective reactance $AB + HP$. BF is the impedance of the secondary circuit; the current induced in it per ampere in conductor (see formula 7) is equal to $CB \div BF$. If there be another secondary circuit beneath, whose reactance is CI, the voltage induced in it is equal to IP. If the current coil of a wattmeter be in series with the main conductor and the volt coil be connected to the terminals of this circuit, the reading will be the watts lost in the closed secondary circuit.

In the case of an iron-armored cable, where there is considerable loss, it is impossible to calculate the conditions accurately, but the following method has given results in fairly close agreement with actual tests. The open circuit conditions must have been measured or calculated from observations on another cable.

The construction is as follows: (refer to Fig. 9) OA equals the conductor resistance; AB equals the reactance between sheath and conductor and may be calculated by formulas 13 and 14. OL equals loss when the secondary circuit is open; OK equals impedance. The circle BKC is constructed, its center being on BC. BG equals BC. In the diagram as constructed it was necessary to draw BG one-fourth size, thus reducing GM and BM to the same scale, on account of the great length of GM. This affects no other lines or points. GM is perpendicular to OL. Draw BKM, cutting MG in M. Then OK is the impedance which would have resulted had there been an imaginary completed circuit of reactance BC and resistance GM surrounding the conductor so as to have a reactance between itself and the conductor are equal to AB.

This assumption is actually far from true. A large part of the loss, probably one-half or more, in the tape-armored cable is due to hysteresis. The excuse for the method is that errors in calculations based on it are less than the variations would be between two cables made to the same specifications. For the remainder of the calculation consider this imaginary circuit in parallel with the sheath when the latter is connected. The point P may be located as before, OP being the impedance of the cable. The voltage induced in the lead on open circuit is BK. The current is determined as before, except that the whole current (equals *CB* + *BF*) may be supposed to divide between the two in accordance with the resistances.

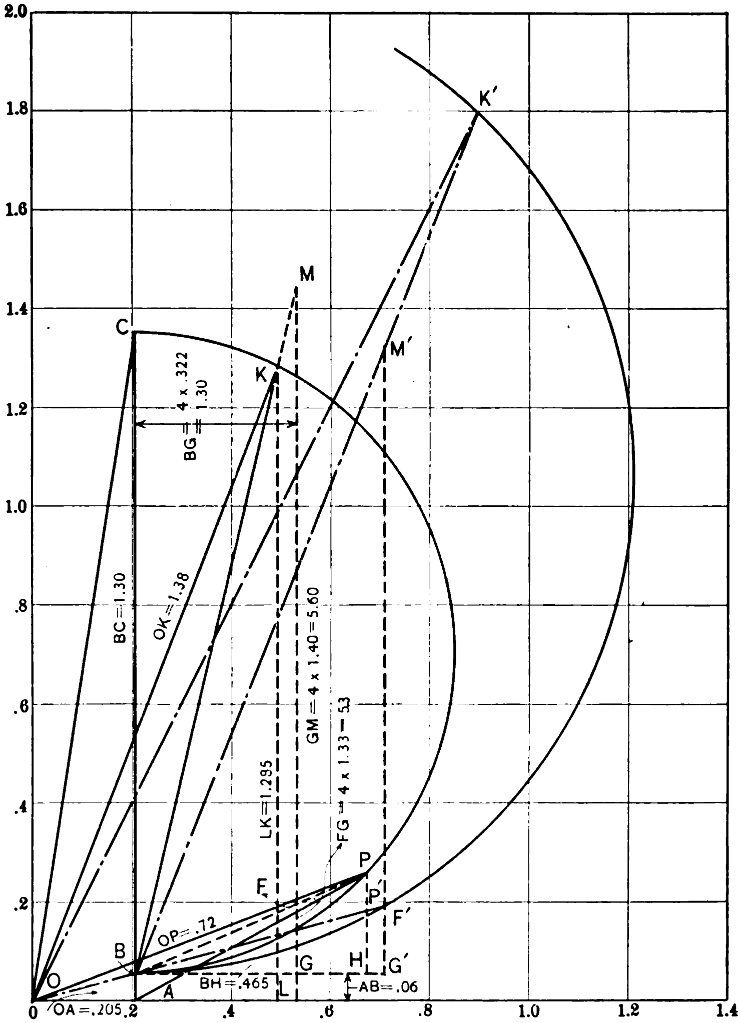

FIG. 9.

It may be noted that the accuracy of any method for calculation of the performance of an iron-armored cable is somewhat reduced, due to the fact that the reactance voltage caused by the iron is far from a sine wave.

In demonstrating the correctness of the construction for the cable without iron the following facts are made use of.

1. The effect on the magnetic field, of current flowing in a tube, is the same at any point outside the tube as if the current in the tube were concentrated in a conductor at the axis of the tube.*

2. The effect on the field at any point inside the tube is zero.*

From (1) it follows that the electromotive force induced in the tube is the same whether the current be flowing in the tube or in a conductor at the axis of the tube.

The effect of non-uniform distribution of current in the tube when the cables are near each other has been neglected. This effect should be of about the same magnitude as that of the eddy currents produced by the current in the conductor when the secondary circuit is open. This latter effect is, in general, not of great importance.

Let current in conductor = I.
$x+x_1$ = reactance of conductor,
x = reactance of tube (lead or armor).
xI = volts induced in tube when tube circuit is open.
r = resistance of tube,
r_1 = resistance of conductor.
i = current induced in tube.
i_1 = component of i in phase with I.
i_2 = component of i at right angles to I.
E = voltage.
E_1 = voltage in phase with I.
E_2 = voltage at right anangles to I.
Induced by the flux which cuts both the tube and the conductor when the tube circuit is completed.

Now since the induced voltage is at right angles to the current producing it and is equal to the product of that current by the reactance of the circuit,

$$E_1 = i_2 x \qquad (1)$$

$$E_2 = (I - i_1) x \qquad (2)$$

Then since E_1 and E_2 are the voltages induced in the tube by the combined action of the current in the conductor and in the tube itself, the current induced is equal to the voltage divided by the resistance, and is in phase with the voltage producing it, or

---

* See Maxwell, Third Edition, Vol. II, page 316.

$$i_1 = \frac{E_1}{r} \tag{3}$$

$$i_2 = \frac{E_2}{r} \tag{4}$$

From equations (1), (2), (3), and (4) we obtain:

$$i_1 = \frac{x^2}{r^2+x^2} I \tag{5}$$

$$i_2 = \frac{x\,r}{r^2+x^2} I \tag{6}$$

$$i = \frac{x}{r^2+x^2} I \tag{7}$$

$$E = \frac{x^2\,r}{r^2+x^2} I \tag{8}$$

$$E_2 = \frac{x\,r^2}{r^2+x^2} I \tag{9}$$

$$\frac{E_1}{E_2} = \frac{x}{r} \tag{10}$$

If I is made equal to 1, these values are in ohms, volts, and amperes. The impedance of the conductor equals the vector sum of E_1, E_2, x, and r.

If r be eliminated between equations (8) and (9), we get an equation between E_1 and E_2, which is that of a circle constructed on the line x as a diameter. This with equation (10) confirms the correctness of the graphical construction. It is possible to calculate the conditions existing when two secondary circuits of different reactances and resistances are connected in parallel, but the formula is very complicated and is of the fourth degree.. It is much simpler and generally would be very closely approximate to assume a single circuit having a reactance of about the average of the two. This will always give values of the total loss somewhat lower than the true loss.

Having given the performance of one armored cable with the secondary circuits open, that of another of different dimensions may be easily determined almost as closely as one of the same dimensions, provided only that the size of the armor and the method of construction be the same.

Let a_1 = diameter through the center of the armor of the measured cable, a_2 = same diameter on the cable whose performance it is desired to calculate at a current = I. Then the loss of apparent power in the second cable at I amperes caused by the armor is equal to $\frac{a_2}{a_1}$ times that of the first at $I \frac{a_1}{a_2}$ amperes. The loss to be used in the calculation is the total loss in the cable less the conductor $I^2 r$. To get the impedance due to the armor, subtract from the total impedance (vectorially) the conductor resistance and the reactance calculated for cables of the same size at the same separation without armor. More accurately, that part of the reactance which is produced by the space that would be occupied by the armor should not be subtracted. Neglecting this will make an error of about 5 per cent in the reactance.

The formulas used to obtain calculated results given in this paper are as follows:

Inductance of a cable:

$$L = l \frac{15.24 + 140.5 \log 10 \frac{d}{r}}{10^9} \tag{11}$$

l = length of cable in feet.
d = distance between centers and
r = radius of conductor.

$$\text{For tubes—inductance} = l \frac{140.5 \log_{10} \frac{d}{r}}{10^9} = L \tag{12}$$

This is strictly true only for an infinitely thin tube. Inductance of a circuit consisting of a tube and solid conductor

$$= L = l \frac{15.24 + 140.5 \log_{10} \frac{r_1}{r}}{10^9} \tag{13}$$

r_1 being the radius of the tube.
The reactance = $2 \pi f L$ (14)
Where f = the frequency.

In Fig. 8 the construction resulting in the determination of the impedance *O P* was for the 1/0 copper armored cable, distance between centers being 18 in. The impedance *O P′* is that of the same cable, the distance between centers being 1.5 in. Both of these impedances were determined with the armor short-circuited at each end of the cable.

The construction of Fig. 9 is based on a conductor current of 300 amperes and 24 in. between centers of the steel-tape armored cable. The incompleted semicircle *B F′ K′* is the construction for 156 amperes. It is interresting to note the relative increase of reactance compared with ohmic resistance which is much greater in Fig. 9 than in Fig. 8.

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ELECTRIC CONTROL FOR ROLLING-MILL MOTORS

BY C. T. HENDERSON

Much has been said regarding the remarkable electrical applications during the last few years in connection with the iron and steel industry, but only those directly interested in this work realize how much impetus has been given to it by the development of suitable controlling apparatus. When A. C. Dinkey, then chief electrician of the Carnegie Steel Homestead works, installed the first electric motor for roll-table service in 1893, he naturally used the standard apparatus of the day, and quite naturally it failed. He immediately sought for something better, especially in controlling apparatus. At that time the only service comparing in severity with that encountered in rolling mills was in electric railway practice; accordingly, the railway motor was rewound for 250 volts and placed in service. In controllers not even temporary satisfaction was found in the devices available, so Mr. Dinkey developed a simple rheostatic controller of the face-plate type. This controller, or one similar to it, together with the rewound railway motor, supplied the demands for about 12 years. Meantime, however, it was found that mill service was much more severe than railway service—more severe in the number of starts and stops per hour, in continuity of service, in lack of intelligent handling, and in the initial temperature of the surrounding atmosphere. It should be said, too, that the penalties of delay in the mill are much higher. If a car in a traction system is put out of service, it can, at the worst, wait and be taken to the car-barn by the following one, without causing essential money loss. But a steel works is unusual in being a manufacturing plant in which there is no reservoir: the material must pass through in an uninterrupted stream; for a delay at any point breaks up the process all along the line, resulting in the derangement of the entire system, much spoiled steel, and consequent loss.

Again a steel plant is unique in the relation of the initial cost of the installation to the value of the product. The Gary plant, with its large and costly electrical equipment, can roll a value in finished product equal to the entire cost of the plant in a couple of months. So it has come to pass that a steel plant figures that the loss of a blooming mill, for instance, in time of good business, costs somewhere between $300 and $1000 per hour, depending upon its capacity.

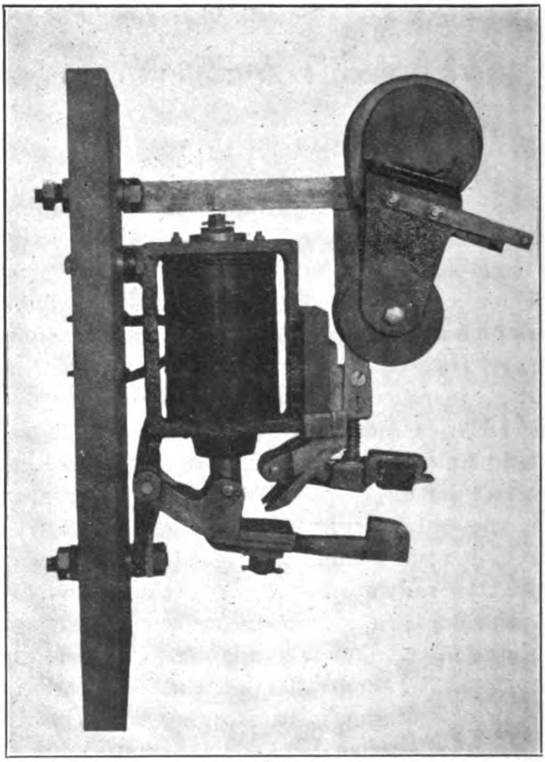

FIG. 1—Contactor type switch

Though in the light of present-day practice the first motors and controllers in steel works were unsuited to the work, they grew steadily in favor, and continued to supplant steam auxiliary apparatus. But as the number of motors increased the dissatisfaction with existing types of controllers increased correspondingly. Series-wound motors with a torque almost directly proportional to the current were hardly satisfactory substitutes for steam engines (whose torque was limited by piston area and boiler pressure) when the controllers were operated by ignorant and often vicious persons. To remedy this defect in the operating conditions, about the year 1900 there appeared various devices for properly controlling the motors. Lack of ruggedness caused most of these devices to fail, and it was not until about 1903 that really serviceable apparatus of this nature came into use. From the start the necessity for current-limit control was recognized, and apparatus was designed to make the period of acceleration dependent on the current supply to the motor, the control system being an

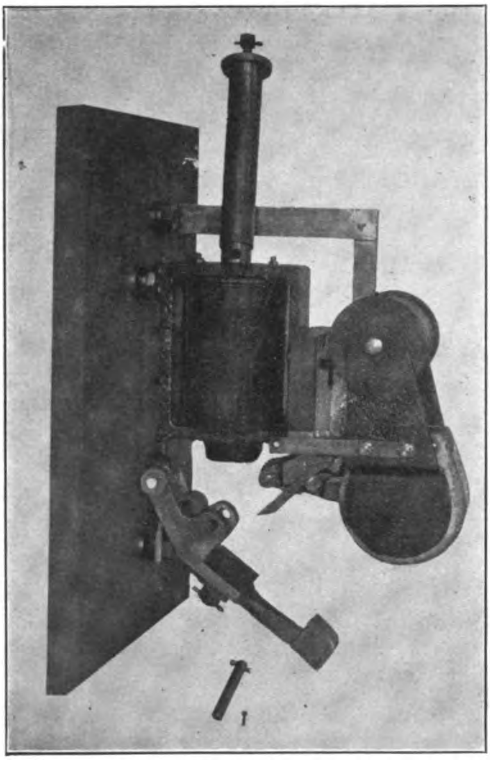

Fig. 2—Contactor type switch opened for repairs

organization of magnetically operated switches whose details left much to be desired on account of the steel mill practice of making repairs on Sunday. At first the demand was for a controller made up of switches rugged enough to operate continuously for 6 days; this was produced late in 1903. Soon there was a demand for a switch more rugged and more susceptible to quick repairs when such were needed.

The importance of minimizing delays in steel mill work has already been touched upon. Apparatus of this nature was produced in due time. Its design may be of interest. Fig. 1 shows a typical switch for this purpose. It consists of a cast-steel frame carrying a fixed contact on an insulated block, and having hinged in it a movable contact lever adapted to be moved by the solenoid plunger into and out of engagement with the fixed contact. The main or current carrying contact is of laminated copper, protected

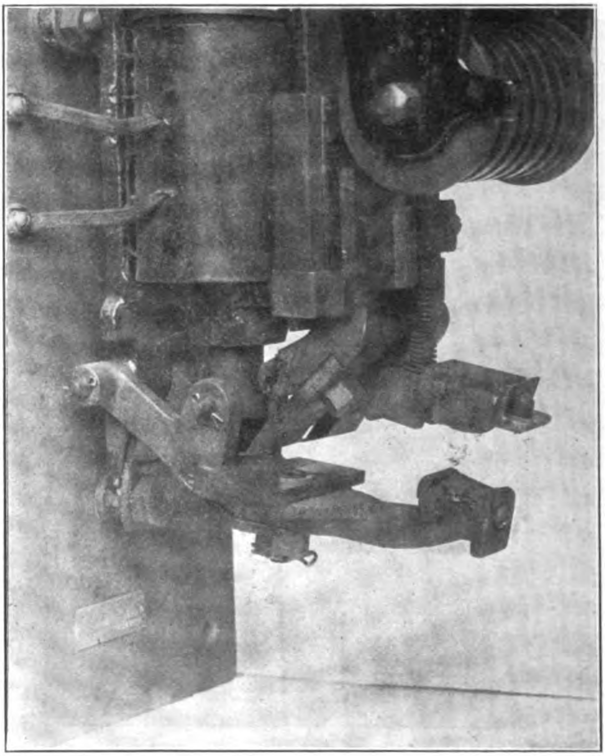

Fig. 3—Contactor type switch after 60,000 operations

from arcing by auxiliary contacts of carbon and copper normally in the field of a powerful blowout. The poles are shown in Fig. 1, swung up, as they are in practice, to facilitate inspection and repairs. In designing this switch the strength of the materials used was determined by the destructive power of the average repair man. The arrangement of parts is laid out to minimize the probability of delay, should the parts break. For instance, the carbon auxiliary contact is so placed that it will be actuated by gravity should its spring be broken.

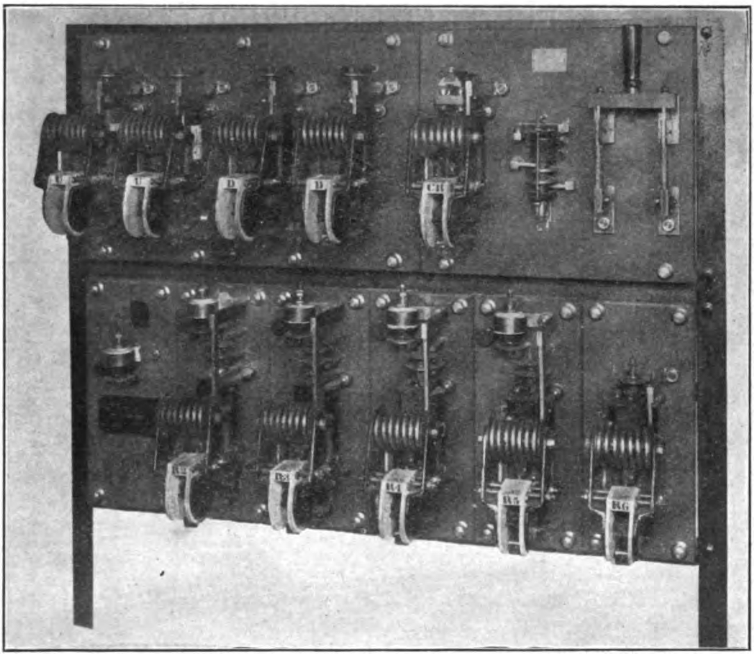

Fig. 4—Contactor type switchboard

Every effort has been made to minimize the time required for replacing defective parts; for example, new arcing contacts can be put in in 15 sec., a new arcing contact spring in 20 sec., a new magnetizing coil in 1 min. 40 sec. (Fig. 2). In case of serious trouble, the switch being self-contained, it can be removed from the board as a unit, replaced by another, and then taken to the shop to be repaired at leisure. This exchange has been made with a delay of 1 min. 30 sec. Numerous experiments and observations seem to indicate that the life of contacts on a switch of this kind varies inversely as the square of the number of operations per minute.

Fig. 3 shows a contactor after opening and closing a high inductive circuit carrying 120 per cent in excess of its normal rating 66,000 times at the rate of 30 operations per min. Both auxiliary contacts have about reached the end of their life, and hence require renewal. Reduced to 10 operations per min., which is about the average rate, this switch should operate about 600,000 times without requiring renewals, and longer under normal load conditions instead of 120 per cent overload. In service this type of switch has operated over 1,000,000 times without repairs.

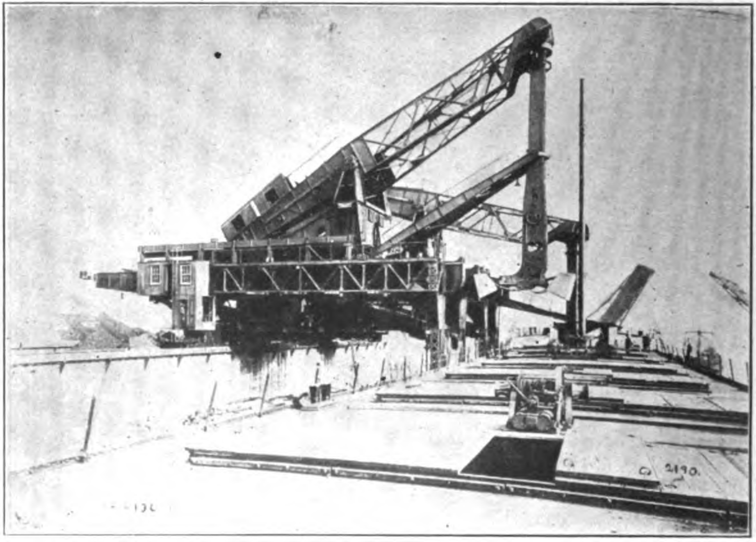

Fig. 5—Hewlett unloader

It has been said that the necessity for current-limit control was recognized very early. The first systems employed were far too complicated. Further, they were adapted to maintain the accelerating current at an approximately constant value. In many instances this is undesirable; for instance, where motors are reversed while in rotation, the high armature reaction makes them incapable of commutating current that could be commutated safely when starting from rest. Again, as the motor comes up to speed its commutating limit falls off. This is taken care of in modern controller practice by having a multiplicity of current relays, one associated with each accelerating switch, so that the current can be adjusted independently at each point in the cycle. (Fig. 4.)

Starting at the docks where the ore is unloaded and shipped to various steel plants, we find one of the most spectacular machines in the steel industry, the Hulett unloader. Figs. 5, 6, 7, and 8. These machines were originally steam-hydraulic operated, and have been successfully electrified only during recent years. The operator rides in the bucket-leg and controls all motions of the unloader. The walking-beam carrying the bucket-leg must be started smoothly and quickly when the bucket has been filled, then slowed down and stopped automatically at the top. In lowering, the hoist motor must be transformed into a generator and serve as a retarding means.

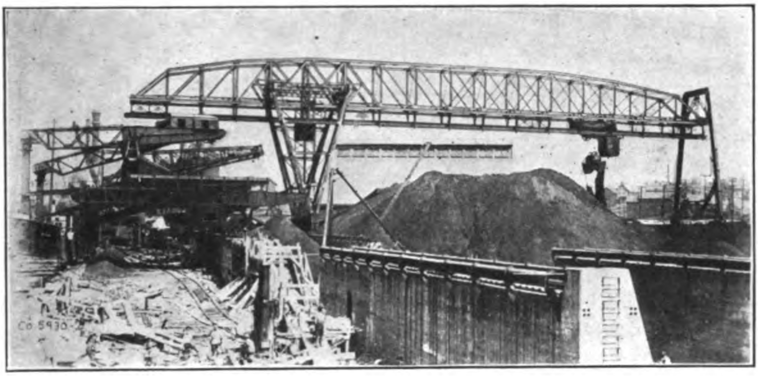

Fig. 6—Hewlett unloader

At the bottom, when the operator throws his master controller to the " off " position, the beam must be brought to rest quickly and smoothly. This is accomplished by the same current limiting devices used in acceleration. So perfect are the results obtained, that riding in the bucket-leg reminds one of a trip in a hydraulic elevator.

The bucket which handles 10 tons per trip can be rotated so as to pass between hatches, and automatic control of this motion serves to limit the rotation to seven-eighths turn either way from the normal position. The bucket having been rotated 90 degrees, it is easily seen that if it should get caught on a stanchion while closing, the enormous side strains would be thrown on the supporting beam. This distinctly calls for current-limit control of the highest order. Since such apparatus has become available, it is possible to reduce the weight of the machine 15 per cent by reason of the elimination of these extraordinary strains.

During the present season four such machines of 15 tons capacity per trip are being installed. Aside from their huge size they have many interesting features. They are made to span five railroad tracks, and carry a weighing larry that runs across these tracks. The bucket conveys ore from the hold of a vessel into a hopper, from which it is drawn into the larry and weighed. From the larry it is dumped into railroad cars, being weighed by subtraction on especially constructed scales during the process. Thus the cars are loaded and weighed without the necessity of first weighing the empties. Furthermore, each car is loaded to its capacity, a feature of great importance to docks whose daily tonnage is limited by the cars available.

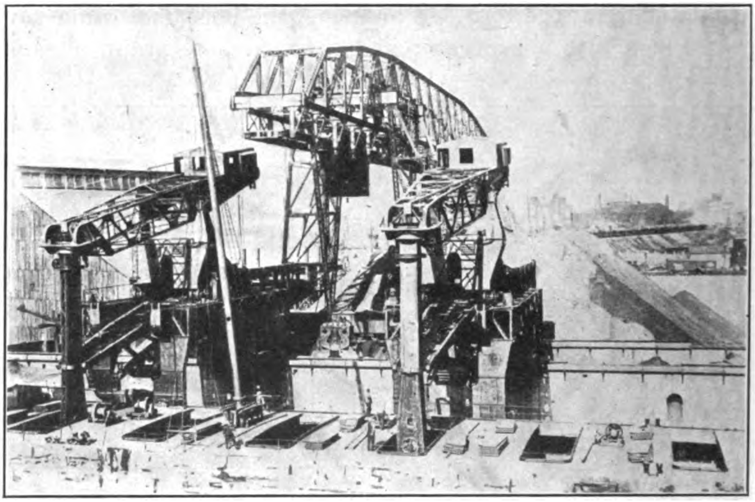

Fig. 7—Hewlett unloader

In ore-bridge practice the availability of proper controlling apparatus has brought about a change in design but little short of revolutionary. To-day in grab-bucket hoists in place of the single motor of 15 years ago, we have the double-motor system, in which the drums are driven by individual motors, thus eliminating the friction clutches, and, by making the operator's physical task easier, increasing the capacity of a given plant. These same motors, equipped with current-limiting, dynamic-braking controllers, can be made to act as generators during lowering, thus retarding the downward movement of the bucket, and transforming the kinetic energy stored therein into heat in a rheostat. Here its conversion is not attended by mechanical abrasion, and hence the necessity for continual adjustments is eliminated. During the lowering operation the braking of either of the two motors can be varied independently, and thus the bucket made to open gradually, close gradually, or remain with the jaws at a fixed opening, as desired.

In the steel plants themselves the complete electrification of auxiliary machinery was not attempted until sometime after both controlling apparatus and motors had been brought to a condition closely approaching perfection. As late as 1905, steel plants were erected in which all auxiliary machinery (except the blooming-mill tables and elevating mechanism in the case of three-high mills) was electrically operated. Gradually the prejudice against electrically operated blooming-mill tables was overcome, but the elevating-table mechanism seemed destined to remain hydraulic. When the problem presented is considered carefully, the hesitancy on the part of the mill owners must be acknowledged to be justified. The elevating tables referred to consist of live rollers which must be elevated or lowered between passes, first to admit the steel to the lower pair of rolls, then return it to the upper pair. The rolls are very heavy, seldom weighing less than 100,000 lb., and must be operated in

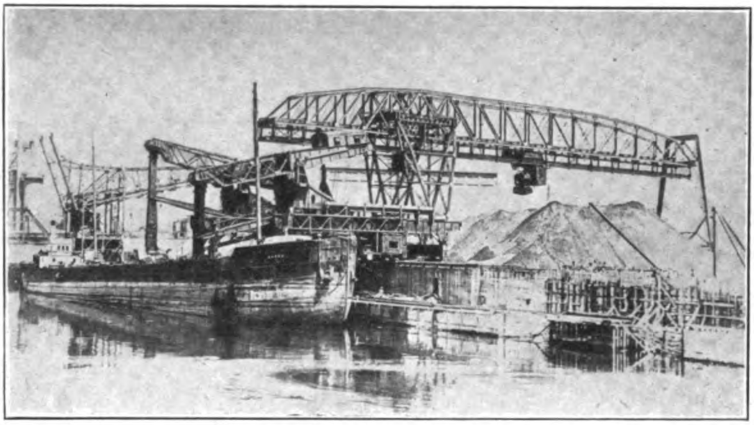

FIG. 8—Hewlett unloader

very short periods. At last a steel plant was found which was building a new 40 in. blooming mill; this plant was willing to put in the electrically operated table mechanism, if it could be shown to be feasible. A careful investigation of the speed in other plants showed that the shortest period required by hydraulic equipments to raise or lower was 3 sec. To insure the table being fast enough, the steel company's specifications required a complete cycle in 2.5 sec., apparently on the supposition that the equipment would not come up to specifications, and that by specifying a 2.5 sec. period they would insure operation in 3 sec. This table weighed 118,000 lb. and was required to rise a total distance of 40 in.

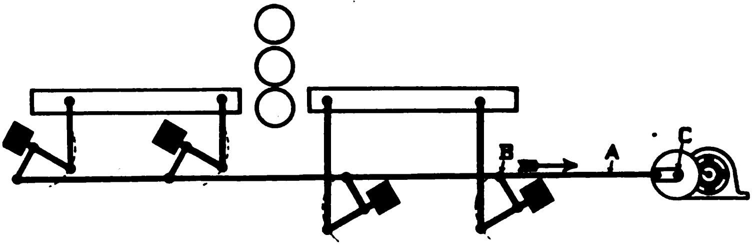

FIG. 9

The arrangement adopted is shown diagramatically in Fig. 9. The motor finally decided upon was 160 h.p. at 88 rev. per min., geared to a crank at a ratio of 1 : 5.8. This crank is connected to four bell-cranks carrying the table. The bell-cranks also carry counterweights aggregating 89,500 lb., giving a total mass of 207,500 lb. to be moved. The ingot to be rolled weighs 10 tons, and the counterweights are so disposed as to counterbalance the table and ingot. Thereafter the problem becomes merely one of starting and stopping, but with enormous masses and unusually short time-periods involved. If the connecting rod *A* were of infinite length, plotting the movement of point *B* in the direction of the arrow against

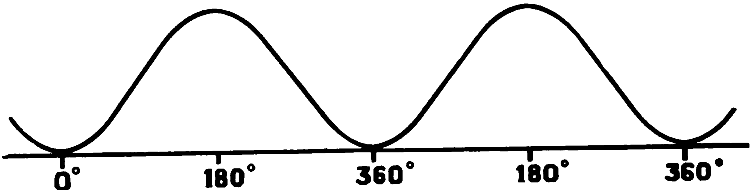

FIG. 10

the degrees of rotation of crank shaft C would result in a true sine curve, Fig. 10. Taking this curve as a basis, it is easily seen that during the first few degrees of rotation there is but little movement imparted to the connecting rod and hence to the table. This being true, almost the entire starting torque of the motor is available for accelerating its own armature; and if it is accelerated before the curve begins to rise abruptly the full torque will then be available for accelerating the table and counterweights. At the top the table is decelerated by virtue of the shape of the curve, the full torque of the motor being again available for retarding its own armature. While the connecting rod used in actual practice is so long as somewhat to distort the rotation-movement curve, Fig. 10, at the same time this curve is close enough to that obtained in practice for an understanding of the installation.

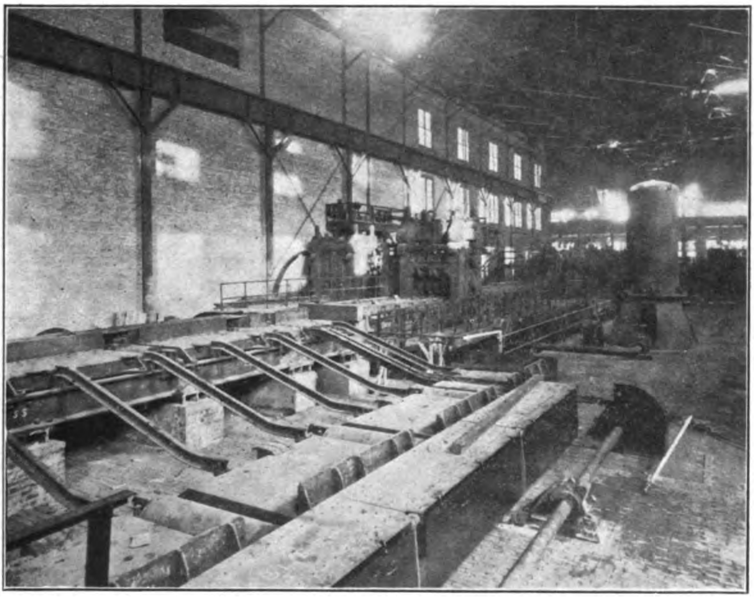

FIG. 11—Three-high blooming mill with motor-operated elevating table

The first installation worked out very well indeed. The table rose in 2.4 sec., 0.4 sec. of this period being required to accelerate and 0.4 sec. to stop, the motor operating at full speed 1.6 sec. Recording ammeter charts show that this is accomplished without the motor requiring more than full-load current at any time. The controlling mechanism is entirely automatic, a movement of the operator's master-switch causing the table to rise and automatically slow down, and stop, while a reverse movement causes it to lower automatically, slow down, and stop. Although there is a solenoid operated brake on the equipment, its time-lag is such that it never acts until the table has been brought to rest by generative action. The shape of the rotation-movement curve is again of value in that a few degrees of error in the stopping point, top or bottom, does not influence the position of the table to any extent.

The objection to the installation just described is the necessity for accelerating and stopping the counterweights at either end of the cycle, which adds considerably to the power required to operate. Therefore when the table for the blooming mill at Gary, Fig. 11, was designed, hydraulic counterweights were employed. The bell-cranks carrying the table are connected to hydraulic cylinders piped to the compression tank partly filled with air. When the table is down the air pressure in the compression tank over-counterweights the table by 25 per cent. When the table is up it is under-counterweighted by 25 per cent. This is accomplished by a proper proportion of air and water in the system.

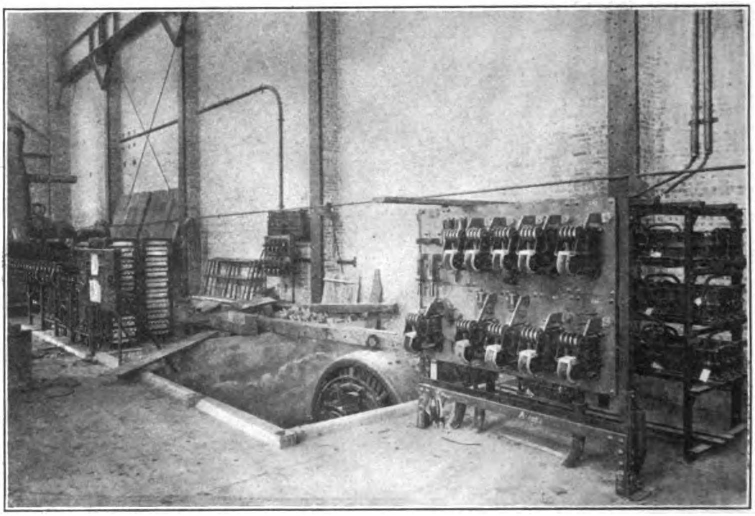

FIG. 12—Contactor type controlling panel for 200-volt, 250-h.p. direct-current motor used to raise and lower blooming-mill table

The Gary table moves 43 in., weighs approximately 250,000 lb. and makes a cycle in 3 sec. It is operated by a 250-h.p. motor running at 100 rev. per min. Immediately after completion of the Gary table, an interesting test was made to determine how closely the acceleration curve followed a true sine wave. A board carrying a paper chart was placed on the side of the table, and an electric bell with clapper removed and a pencil substituted connected on a 25-cycle circuit and arranged to make dots on the chart. Connected on a circuit of this frequency, it would make 50 dots per second. The distance between dots served as a guide in the compiling of a curve which, considered with the recording ammeter chart, shows the motor to be up to speed when the table begins to rise with any rapidity. Unfortunately a copy of this accelerating curve is not available for presentation at this time.

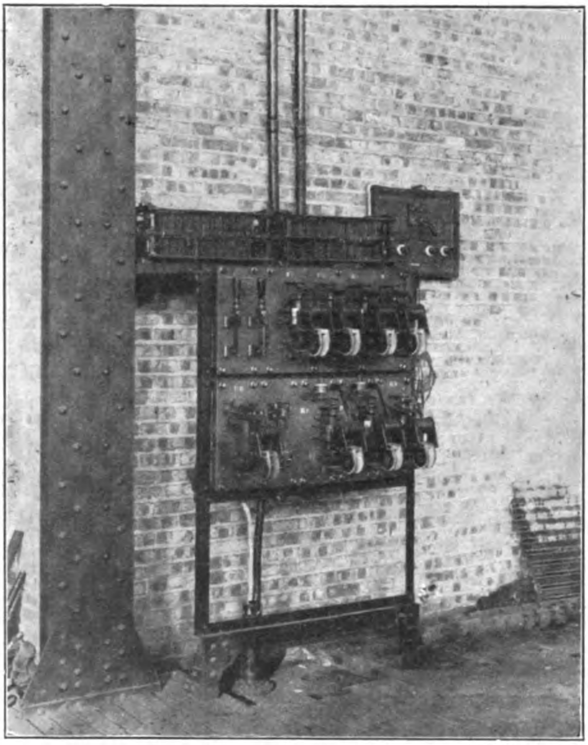

FIG. 13—Typical contactor type controller panel

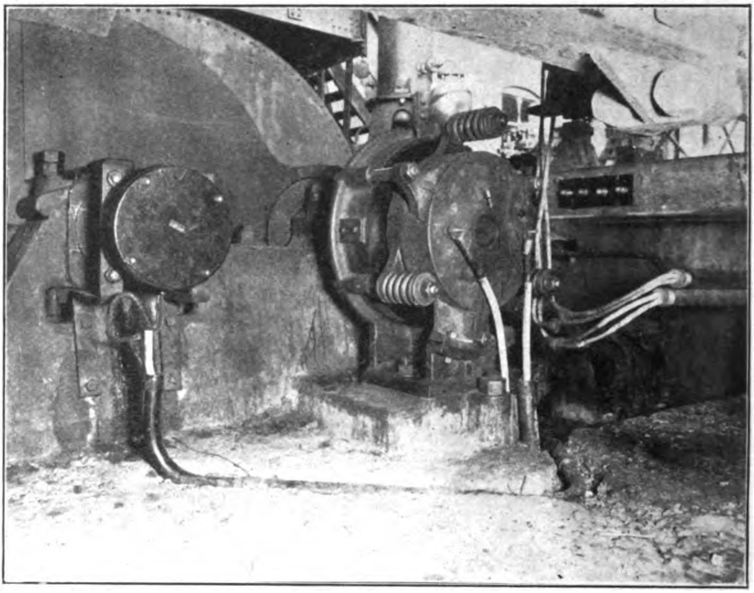

FIG. 14—View underneath tilting table of three-high roughing mill, showing automatic limit switch and disc brake

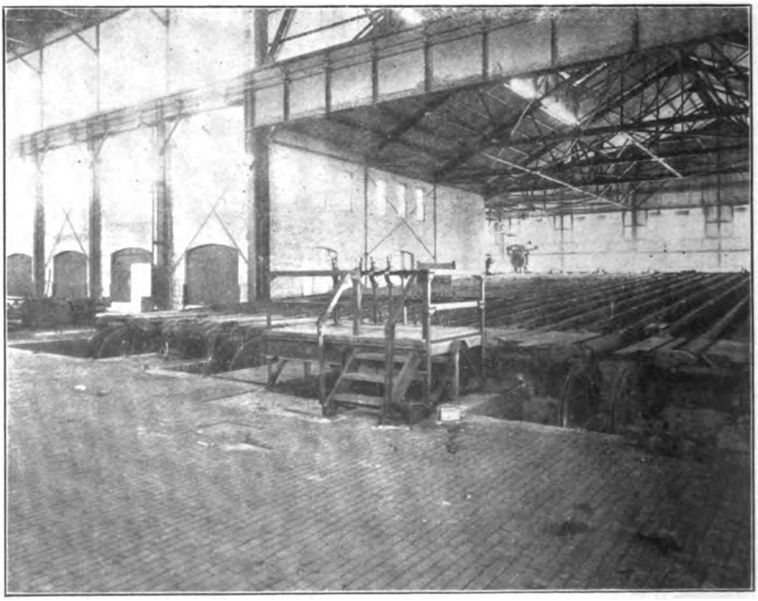

FIG. 15—Hot bed with pulpit containing master switches for rake-offs and drag-outs

The Gary plant is filled with interesting automatic controllers. The completeness and effectiveness of the installation can be appreciated when it is considered that eight operators are able to turn out 100,000 lb. of rails per month. One of the most unique features of the plant is the automatic coal skips. Coal is delivered to the gas producer houses in standard railroad gondolas, from which it is dumped into a hopper. From here it goes through a crusher, and thence to the coal skips, which are of the double-balanced type, and arranged to dump into the bins, from which the producers draw their supply.

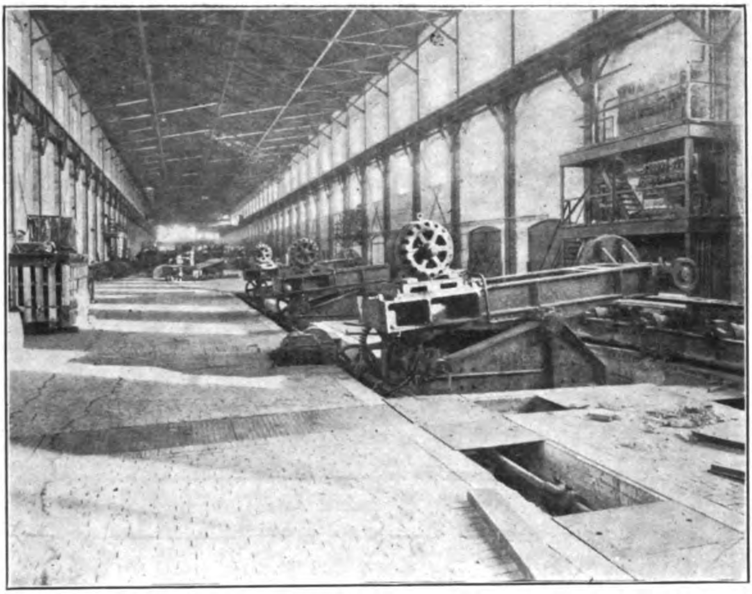

Fig. 16—Hot saws for sawing steel rails

When at the bottom, the skip-car automatically opens the chute-gate and rests on one end of a counterweighted lever. If there is any coal coming through the crushers, it will feed into the skip; if not, the entire equipment will remain inoperative. As soon as a certain quantity of coal has been fed into the skip-car it overcomes the counterbalance. This action starts the motor driving the hoist. In leaving the bottom position the chute is closed, and when the first skip-car is dumped, a second is at the bottom and ready to take coal. This automatic action continues as long as there is coal to be hoisted, a counting device for registering the number of trips being a fairly accurate indicator of the total tonnage of coal handled.

While this electrification of auxiliary apparatus has been going on, there has also been great progress made in the electrification of the rolls themselves. No electrical engineer is overoptimistic in believing that another 10 years will see the complete elimination of all motive power other than electricity in steel plants. In fact the only question to-day seems to be whether auxiliary apparatus of a reversing character shall be operated by alternating current or by direct current. Experiments now being conducted at Gary, where both types will soon be installed, may lead to some definite conclusions on this subject.

A paper presented at the 26th annual convention of the American Institute of Electrical Engineers, Frontenac, N. Y., June 30, 1909.

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ELECTRIC POWER PROBLEMS IN STEEL PLANTS

BY R. TSCHENTSCHER

Previously to September 1904, the capacity of electric power plants in American steel mills varied locally from 200 to 3000 kw. The largest units were of approximately 1000 kw. capacity, and only direct current at a pressure of 250 volts was used. Plans in contemplation over a year before 1904 resulted in the construction of the first steel mill power plant of any magnitude at the south works of the Illinois Steel Company. This plant consisted of a 4000-kw. station composed of two 2000-kw. 25-cycle, three-phase, 2200-volt steam-engine-driven generators. It was put in operation during September 1904, and supplied two converter sub-stations, transformers for local alternating-current motors, and a 22,000-volt transmission line 10 miles long supplying alternating-current motors at a cement plant. Since 1904, many of the comparatively small electric power plants in steel mills have been increased to several times their original capacity.

Steel mills may be divided into four general classes; namely:

A. Finishing mills, or those that buy steel in the shape of blooms or billets and reduce them to a commercial form.

B. Steel-making mills, or those that buy iron and other materials needed in making steel. These mills are equipped with steel furnaces, and reduce their product to a commercial form.

C. Self-contained steel mills, or those that buy the raw materials necessary to make iron. These mills are equipped with blast furnaces, steel furnaces, and rolling mills for finishing the product.

D. Self-contained steel mills which also supply power to auxilliary plants, such as cement mills, or to other consumers.

A. The electrical problems differ somewhat in the mills as classified above. In finishing mills the electric plant usually consists of a direct-current, steam-driven station of from 200 to 1000 kw., supplying power for table motors, cranes, conveyors, lights, etc. No alternating-current power is used and the maintenance is a simple matter. The future problems of such a plant may result in the installation of motors to drive the mill rolls, replacing wasteful non-condensing engine and inefficient boiler equipment, and the installation of a modern efficient generating system, either steam-turbine or producer-gas-engine-driven (unless natural gas is available). The matter of installing storage-batteries and other refinements is a local one.

B. In existing steel-making mills the electric plant, though similar to that of plant *A*, is of somewhat larger capacity, ranging from 400 to 2000 kw. The power demand is also for a similar purpose, and a mixed alternating-current and direct-current system is not required. The future problems of such a plant are similar to those of plant *A*. The development of the electric steel furnace may, however, be such that a commercially feasible equipment might result and "cold metal" (pig iron, scrap, etc.) be converted into steel, thus doing away with cupolas or Bessemer converter installation. The electric power problem would then be materially altered, as described later.

C. In existing self-contained mills, the present problems are so diversified that a generalization is not as feasible as in the two preceeding classes. The electric plant problem is virtually a local one. A few general remarks may, however, be made. The electric power plants of such mills range from 500 to 10,000 kw. capacity, the larger capacity depending upon whether motor-driven rolling mills are in service, and other considerations of large power demand. In plants without motor-driven rolling mills a single direct-current system often exists, which, when properly arranged, makes for a decidedly simple and easily maintained equipment. The power demand consists of: 1. Ore-handling equipment, such as unloaders, conveyors, distributors, etc. 2. Sundry blast-furnace service, such as raw material supply cars, skip hoists, etc. 3. Steel-furnace application such as raw material, hot metal and scavenger cranes, charging machines, stripper cranes, etc. 4. And for the sundry rolling mill purposes as previously enumerated.

In mills without large concentrated power demand the problem of installing storage-batteries is a local one, and will depend frequently on the ore-handling equipment. If this be considerable, or if located some distance from the power plant, then questions of power-plant capacity or of voltage at the ore-handling plant may be solved advantageously by proper storage-battery installation instead of added direct-current generators in the former case and alternating-current generators and converters in the latter case. Where such ore-handling load does not exist, the station power fluctuations will in general not be over 10 or 20 per cent, and sufficient generating equipment only is needed. This equipment may be operated at a high load-factor, the necessary maintenance being attended to on Sunday when the rolling-mill load does not exist. The desirable arrangement of simplicity and uniformity of equipment which exists in every industry is most pronounced in mill work on account of the comparatively large repair expense, the inefficient operatives, and the costliness of delays. Therefore, a single generating system with simple distribution is desirable and feasible in plants of this kind.

In plants with motor-driven mills or other sources of considerable power demand, the problem becomes rather complicated. Again it is one of local treatment, though no doubt a few general principles may apply. The generating requirements will in most cases result in an alternating-current equipment. If the plant is an existing one and inefficient rolling-mill engine and boiler equipment is to be replaced by motors operated by means of efficient power generated in the vicinity of the blast furnaces so that blast-furnace gas may be utilized, then the commercial limitations will not usually admit of replacing the existing direct-current generating station. A second station must be built, either adjoining the direct-current station or at some more advantageous point. Proper electrical connecting apparatus between the two stations must be supplied. This will usually consist of a converter floating between the two station bus-bars. The advantage of this arrangement cannot be overestimated, as operating conditions will usually be such that at stated intervals (Sundays) either station may be shut down in whole or in part. The selection of proper alternating voltage may also be a local one, though the experience of the last 5 years shows that the increase of electrical application in steel mills is so rapid that a pressure of less than 6600 volts for local generation and distribution will no doubt result later in an unwieldy arrangement of switchboard and cable equipment and distributing feeders. The frequency of 25 cycles, now used almost exclusively, is most suitable, and nothing has yet appeared to indicate that a higher or a lower frequency would be more desirable.

D. It will no doubt be of some interest to discuss specifically a few of the electrical problems encountered in a large steel mill. For this purpose the plant of the Illinois Steel Company at South Chicago, Ill., will be outlined. This plant comes under classification *D*, previously referred to; namely, self-contained steel mills which also supply power to auxiliary plants such as cement mills, or to other consumers. Naturally enough, it is in such plants that the greater variety of electrical problems exists and where electrical application will be most extensive.

The South Chicago Works of the Illinois Steel Co., is a good example of the self-contained steel mill. Its development during the last 5 years has been remarkable. Prior to September 1904, the electrical equipment of this plant consisted of a direct-current generating equipment of 2900 kw. at 250 volts pressure. Even at that time this was the largest electrical installation in an American steel plant. The electrical power demand consisted of that usually found in mills under classification *C*; namely, all classes of cranes, mill tables, and miscellaneous equipment, illumination etc. Since that time additional blast furnaces, ore-handling equipment, steel-making mills, finishing mills, and two cement plants have been added. Where steam engines had been used at blast-furnace skips, motors were installed and the cost of operating was reduced. Where steam engines had been used for ore handling and for all new ore-handling equipment, motors were installed, the output increased, and the cost reduced. Where new rolling mills were designed, motors on the main rolls were specified, with consequent increased tonnage at lower fuel and maintenance costs. Where new cement mills were installed, motor drive was employed throughout and power obtained by means of high-voltage transmission lines from an efficient power plant. Again the output was increased and the cost reduced.

Without going further into details, the electrical installations at this plant have during the last 5 years resulted in an equipment approximately as follows:

Number of motors, both alternating current and direct current	2,000	
Total motor horse power	75,000	
Total number of arc lamps	1,500	
Total alternating-current generating equipment installed	16,000	kw.
New alternating-current generating equipment being installed	9,000	“
Total direct-current generating equipment installed	3,000	“
Total generating equipment	28,000	“
Total synchronous converter (and transformers) and motor-generator equipment	6,500	“
Total storage-battery equipment	1,200	“
Total transformer equipment	31,000	“

The variety of the equipment may be judged from the various existing voltages; namely, 250-volt direct current; 110, 440, 1100, 2200, and 22,000-volt alternating current. This plant comes under the heading of " evolution plants "; that is, plants wherein steam and hydraulic equipment have been in process of replacement by electrical equipment. The solution of the various problems in such a plant does not result in the more desirable and simple systems which will be found in future new plants, for in the new plants the large variety of voltages mentioned above will surely be avoided.

One of the problems in steel mills now receiving considerable attention, and which in the future will be one of the real engineering problems, is the conservation of waste heat. The existing waste heat at open-hearth furnaces forms an enticing point of attack; this waste may be eliminated by replacing such furnaces by electric steel furnaces. These furnaces will be mentioned later. However, the waste heat at rolling mills does not as yet appear to be capable of satisfactory elimination. All steel before being rolled must be heated so that an even temperature and hence even consistency throughout the piece will result. Producer-gas furnaces are now used almost exclusively for this purpose. The stack temperatures are usually very high, being between 800 and 1200 degrees fahr. These temperatures may readily be reduced by passing the gases through suitable steam boilers to provide steam for turbine-generators. It is not at all improbable that instances exist where with proper installation of boilers, regenerators, turbine-generators, and roll motors, a rolling mill may be made a self-contained unit, obtaining from its present waste heat sufficient power to supply electrically the entire requirements of the mill, including the roll motor, table motors, crane equipment, lights etc.

The utilization of the energy remaining in the exhaust from non-condensing engines and from compound engines is now receiving serious consideration, the large amount of energy being wasted in engine exhaust steam in non-condensing engines being roughly estimated at 50 per cent of the total available energy. The rolling-mill engine appears to offer a very desirable point of attack in this connection. However, the writer wishes to emphasize that there are many other places in most steel plants where this problem might better be attacked from the standpoint of permanent equipment. By attaching a low-pressure turbine equipment to the exhaust of a non-condensing rolling-mill engine, a premium is put on the retention of that engine in service. The superior operating and cost advantages of motor drive over reciprocating-engine drive (with accompanying boiler equipment) cannot be taken advantage of. The steam engine with a tail in the form of a turbine-generator will be much more difficult to get rid of. It would therefore appear that the other weak points about the mill should be first seriously investigated.

The steam-engine blowing equipment at many blast furnace plants consists of well built compound engines. The possibilities here for low-pressure turbine installation are very great. At a plant which recently came to the writer's attention, four blast furnaces receive blast from eight modern condensing blowing engines. Roughly, the amount of steam required by these engines is 300,000 lb. per hr. By the addition of less than 100,000 lb. these engines develop their required power with exhaust at 16 lb. absolute. These 400,000 lb. of steam would be sufficient to supply a low-pressure turbine-generator capacity of approximately 15,000 kw. The power station installation might consist of three 5000-kw. units. Sufficient power would be available to convert all the mills at this plant to electric drive.

One of the electrical problems at the plant of the Illinois Steel Company which may be of interest concerns the installation of additional generator capacity. A solution of the problem which contains many admirable points was an installation of a low-pressure turbine so designed that high-pressure steam up to full capacity will be economically utilized. Compound condensing reciprocating engines in the power station and in an adjoining blowing engine station will normally supply the steam for this turbine which will be of 9000 kw. capacity. Each compound engine will be so arranged that it may exhaust into the present condenser, or into the turbine main at slightly above atmospheric pressure. In case of insufficient low-pressure steam, the deficiency may be supplied from the high-pressure main, the turbine being so arranged that this high-pressure steam will be economically employed by means of a separate valve and nozzle chamber. Should no low-pressure steam be available, the full capacity at high-pressure steam may be obtained. The condensing equipment will be adequate, the yearly calculated vacuum averaging better than 1 in. absolute pressure. Reliability and economy are the predominating features in the installation. The operation will be watched with interest and it is expected that gratifying results will be derived.

Another problem at this plant which may be of interest was the improvement of the power-factor. The installation of alternating-current roll motors, miscellaneous small alternating-current motors, and the expansion of cement mills where the sole drive is by induction motors, has so affected the power-factor that at present the station power-factor is not over 70 per cent. The largest item in bringing about this condition is a load of approximately 7000 kw. of induction motors at a cement plant supplied by a 10-mile transmission line of 22,000 volts stepped down to 440 volts. Improvement of the station power-factor by corrective means at the cement plant at once suggested itself. This might originally have been accomplished either by the installation of direct-current equipment including motor-generators or synchronous converters or by the use of a considerable number of synchronous motors in place of induction motors. The operating conditions—character of service, cement dust, and inefficient operatives—make the former comparatively impracticable; the additional complication of miscellaneous operation of synchronous motors at proper power-factor by inefficient help makes the latter also undesirable. It is an ever present axiom in steel mill practice that the mill equipment should be simple, rugged, and easy of operation and repair. Whatever refinement and complication may be beneficial should be confined to engine rooms, power stations, sub-stations etc., where labor more skilled in maintaining the equipment may be employed. The foregoing therefore decided that the cement-mill equipment should include the induction motor, the squirrel-cage type being used wherever possible, with simple starting apparatus such as step-down transformers with starting bus-bars, instead of local compensators and starters for each motor.

The question of power-factor correction resolved itself then into the installation of " synchronous condenser " equipment. In order to prove such an equipment commercially advisable, it is of course desirable to have the so-called condenser do mechanical work so that such proportion of its initial cost and operation and investment expense could be charged against it, making the charge for power-factor correction correspondingly less. However, mechanical work of sufficient magnitude did not exist at the cement plant, and the problem resolved itself into determining whether such a synchronous condenser equipment operating idle would prove a commercial proposition. A detailed study of this case was made; the following items give the points at which loss of energy would be reduced, a loss that could be expressed commercially, most of the factors being the components which influence combined efficiency;

a. At station generator fields, due to less excitation being required as the power-factor improved.

b. In station cables and switchboard equipment, on account of less current at improved power-factor.

c. In step-up transformers, due to improved power-factor.

d. In transmission line, due to less current and improved power-factor.

e. In step-down transformers for the same reason.

f. In step-down transformer wiring and switchboard equipment.

To offset the foregoing there is the energy required to operate the so-called synchronous condenser. With a delivered load of approximately 7000 kw. at 70 per cent power-factor, the over-all efficiency is approximately 83 per cent. The installation of two 1650 kilovolt-ampere synchronous condensers will raise this over-all efficiency to 87.5 per cent, the net gain of power being approximately 300 kw. which at 0.5 cent per kw-hr. represents a yearly saving of approximately $10,000. In addition to this, the power station capacity will be appreciably increased, due to the present engine capacity exceeding present generator capacity, and due in a small measure to decrease of excitation load. This gives the commercial aspect. The purely technical aspect of improved operation (regulation and control) due to improved power-factor needs but to be mentioned.

Where alternating-current motors are used to drive rolls, or for miscellaneous mill purposes such as for tables, cranes, etc., where now direct-current motors are used almost exclusively. the power-factor conditions will no doubt require power-factor correction; this may be accomplished by the installation of adequate synchronous condenser installation. The commercial problem will here be rendered more simple, for considerable mechanical load in the nature of air-compressors, pumps, fans, etc., may be supplied to render the charge for power-factor correction materially less than that outlined above.

Before closing, it may be of interest to dwell upon another problem of considerable magnitude which is just becoming manifest. This refers to the manufacture of steel by means of electric power. The Illinois Steel Company has in operation a 15-ton electric furnace of the carbon-arc type. Three 750-kilovolt-ampere, 2200 to 100-volt, 25-cycle transformers are installed. That the making of steel by means of electricity will in the near future be an active commercial proposition in the manufacture of product where now crucible, open hearth, and Bessemer steel is used, is practically an established fact. The extent to which electric power will be necessary for this purpose can easily be conceived to require power stations of a magnitude comparable with those of the largest lighting and railway plants. The writer believes the future will demonstrate that the country's largest power generating stations will be found within the confines of the steel plants. When one considers that a steel making furnace plant utilizing electric power to generate the necessary heat and having a capacity of 4000 tons per 24 hr. requires generating capacity of 20,000 to 30,000 kw., it is not difficult to conceive the magnitude toward which the future steel mill power plant will tend.

Let this thought be carried a little further to illustrate a plant wherein the application of electricity would be supreme. A 2,000,000-ton-per-year self-contained plant where coal, flux, ore, and other raw materials enter and where all classes of steel products, together with cement and the bi-products of coke ovens, leave the plant as finished salable product, might consist of a blast-furnace plant, a Bessemer converter plant, an electric steel-refining plant, a sufficient number of rolling mills, a cement plant, and a coke-oven plant. Such a plant would require electric generating capacity depending largely on the extent to which the finished product is carried. Consider the plant as finishing three-fifths its product as rails, one-fifth as plates, and one-fifth as structural shapes. The total electric power requirements for such a plant would be over 100,000 kw., and it is quite likely that such power could be generated without burning coal for power generation fuel purposes. The so-called waste gases of blast furnaces and coke plants and the utilization of other waste heat will supply more than the required fuel.

If now a plant be conceived wherein the product is further finished; for example, into tin plate, wire etc., a point may be reached where fuel must be obtained from sources other than the usually considered waste sources about the plant. The possible reduction of iron from ore by electrical application, or the manufacture of steel electrically direct from ore, are mentioned merely to show a possibility. The realization of such a possibility would produce a problem the solution of which would result in power plants in comparison with which the foregoing mentioned equipment would be inconsiderable.

DISCUSSION ON "THE CURRENT LOCUS OF THE SINGLE-PHASE INDUCTION MOTOR." FRONTENAC, N. Y. JUNE 28, 1909

(Subject to final revision for the Transactions.)

V. Karapetoff: Professor Langsdorf says that he was induced to write this paper because of certain difficulties that he met with in teaching students. I should like to make one slight criticism from a pedagogical point of view. It appears that Professor Langsdorf wanted to get closer to the physical phenomena, and therefore he discarded Ferraris' assumption of two fields revolving in opposite directions. But he introduced another assumption which, while it may be clear to us, is by no means self-evident to the beginner. I refer to the diagram in Fig. 1. He replaces the squirrel-cage rotor by a direct-current armature, or rather by an armature such as used in some single-phase commutator motors, with two sets of brushes at right angles to each other. These sets of brushes are intended to fix in space two fluxes, the transformer flux and the motor flux, as in the single-phase induction motor. The substitution is hardly justifiable from a pedagogical standpoint. A beginner would not see the equivalence of the two armatures directly. Moreover, this substitution is hardly necessary; for it could just as easily be explained to a beginner that the squirrel-cage rotor, when placed in a motor at rest, would act as the secondary of a transformer; that the same squirrel-cage rotor, if revolved in a constant field, would be equivalent to an apparatus whose field is stationary in space. In this case the flux is in a horizontal direction; that is, along the axis *ff*. For these reasons I think that the substitution of the armature with the commutator for the squirrel-cage rotor is unnecessary. Moreover, it is not quite correct. The squirrel-cage secondary adapts itself electromagnetically to the primary flux, because of the possibility of currents in various bars differing from one another: the equalization is accomplished through the end-rings. In the coil-wound armature, on the contrary, currents in all the coils must necessarily be the same, since the coils are connected in series. Therefore, the student may get a wrong impression, especially with regard to magnetic leakage.

The multistage formula (9) looks complicated because Professor Langsdorf uses reactances and resistances instead of admittances. As I understand it, the only reason is that he wishes to introduce the slip or speed, S. Could not the results be presented in a shape more comprehensive to a student by substituting admittances for impedances? In this case there would not be any stages, but an ordinary addition of terms.

A. S. Langsdorf: In reply to Professor Karapetoff's criticism of the form of Fig. 1, I may say that it has been my practice in class-room work to use both methods suggested by him, but it did not seem necessary to go into such detail in the present paper.

In deriving equation (9) there is little or nothing to be gained in the way of simplicity by using admittances exclusively; the form given in the paper lends itself readily to the determination of Fig. 6, from which the remainder of the work follows directly.

DISCUSSION ON "THE APPLICATION OF STORAGE BATTERIES TO THE REGULATION OF THE ALTERNATING-CURRENT LOAD AT THE PLANT OF THE INDIANA STEEL COMPANY, GARY, INDIANA." FRONTENAC, N. Y., JUNE 29, 1909

(*Subject to final revision for the Transactions.*)

Edward Van Wagenen: As described in the paper, the potential across the regulating brushes *n-n* at unity power-factor is caused by the current from the armature through the auxiliary brushes *m-m*, this current reversing as the energy from the series transformer raises above or falls below the value of the opposing field. At other than unity power-factor the armature will be fed with alternating current, causing a displaced field which may be divided into two components; an energy component desired for regulation, and a so-called non-energy component at right angles to it and therefore causing a potential across the regulating brushes *n-n*. This direct action could easily be made small where plants are designed for coarse regulation, but as the strength of the field energy is multiplied by the factor of regulation, I believe this action would be considerable in plants operating on close regulation such as that required where power is taken from a transmission line or close voltage regulation is required on a plant supplying a variable inductive load. With a plant designed for 5 per cent regulation, for example, the strength of the alternating-current field (energy component) must be twenty times that required to give full current through the brushes *m-m*, and at 70 per cent power-factor the energy and non-energy components are approximately equal.

It seems to me that any variation in potential of the source supplying the opposing field would cause variation in the average load, and that the effect of changing the power-factor will be produced when the load on the driving synchronous motor changes, for the reason that the regulation depends on the space-relation between current in the series transformers and the motor armature. This armature displacement takes place whenever there is a flow of current from the brushes *n-n*, as at least part of the energy is derived from the motor and not entirely from the series transformer, as in the case of the converter used in the previous alternating-current plants operating with true energy regulation.

I think that the above outlined factors would cause considerable deviation from the true energy regulation, thus causing fluctuations on the generating equipment.

J. L. Woodbridge: When I undertook to prepare this paper I expected to have an opportunity to make a good many more tests and observations on the plant at Gary than I have been able to make. The delay in the installation of the second converter, which is only just now being put in service, and the necessity of keeping the first one in commercial operation, has prevented the making of tests which I hope to make later, when there is one spare machine on which I can work.

In regard to Mr. Van Wagenen's point, I think he has failed to distinguish between current out of phase and field out of phase in the exciter. If the power-factor is not unity, there will be a component of current transmitted to the armature at right angles to the energy component, but that component will pass directly through the short-circuit across the auxiliary brushes, and not through the armature winding, inasmuch as the former is a path of very low resistance. That component will not produce a field at all, and consequently will not affect the regulation.

DISCUSSION ON "COMPARATIVE COSTS OF 25-CYCLE AND 60-CYCLE ALTERNATORS." FRONTENAC, N. Y., JUNE 30, 1909

(Subject to final revision for the Transactions.)

J. C. Lincoln: In Fig. 2, the curves showing the costs of 25-cycle machines, the cost of the armature copper, and the cost of the field copper lines cross each other at 2500 kw., showing the costs to be approximately equal. I have always thought that in a large machine the cost of the field copper would be several times that of the armature copper. Ordinarily the air-gap is very long in these machines, and that requires a large amount of copper in the revolving field in order to keep down the temperature, also good regulation requires considerable flux. These considerations tend to increase the ratio of the field copper to the armature copper.

Is it not true that in increasing the output of the armature from a 600 to 900 ampere conductor per inch that the excitation has to be raised in almost the same proportion?

M. G. Lloyd: Fig. 10 seems to me somewhat unfair in that in comparing the total cost the 300-revolution machine should include base, shafts and bearings, while the 100-revolution machine does not. Not being engaged in the manufacturing end of the business, I do not know what proportion that cost bears to the total, but it might make quite a difference in the relative value of the costs.

Has Mr. Fechheimer made any comparisons of the cost with regard to the use of silicon steel in the same way? I know that it is not very much used as yet, but it seems probable that it is going to be used in alternators and in motors.

C. J. Fechheimer: With regard to Mr. Lincoln's question, pertaining to the crossing of the field and armature copper cost curves for 25 cycles at about 2400 kw. in Fig. 2. The relationship of these curves depends to a great extent upon the relative proportions of copper and iron. Until recently it was customary to use 500- or 600-ampere conductors per inch in a large generator, with the result that the field copper would be considerably more expensive than the armature copper. It was shown in my previous paper* that, the product of excitation and weight of field copper varies approximately as the number of conductors, whereas the armature copper varies as the square of the number of conductors. Hence it will readily be seen that if the ampere conductors per inch be increased from 550 in a 500-kw. alternator to 900 in a 5000-kw. alternator, the armature copper will increase more rapidly than the field copper as the size of the alternator is increased. These are the values of ampere conductors per inch which correspond approximately to the most economical machines. Sometimes we cannot build the most economical machine, as, for example, as Mr. Lincoln states, the field heating becomes the limiting factor, and we must use a smaller value of ampere conductors per inch than corresponds to the most economical machine in order to keep the field temperature within reasonable limits. In general, however. we can, in large machines with well ventilated, single-layer, edge-wound fields, prevent their temperature-rise exceeding 45 degrees cent. with full load at 85 per cent power-factor, which should be satisfactory.

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*TRANSACTIONS A. I. E. E. 1908, Vol. XXVII, p. 1429.

In regard to Dr. Lloyd's question as to including shafts, bearings, and bases, in Fig. 10. The 300-rev. per min. machines are intended to be water-wheel driven, in which cases the manufacturing companies are required to furnish these parts. Machines of 100 rev. per min. are usually engine-type machines, and with these the generator builder omits the shafts, bearings, and bases—the engine manufacturer supplies them.

As regards silicon steel, we have not made sufficient tests on the material for me to state definitely whether it would pay us to use it or not. I therefore omitted it in this comparison. We hope to make more complete tests in the future.

DISCUSSION ON "ALTERNATOR FOR 100,000 CYCLES." FRONTENAC, N. Y., JUNE 28, 1909

(Subject to final revision for the Transactions.)

John B. Taylor: I wish to ask why, in Fig. 7, the voltage falls off with increasing field excitation?

J. C. Lincoln. I wish to ask why, in the design of a small machine of this sort, such a small diameter as one foot is selected for the diameter of the rotating part. The centrifugal strains would be less with a given peripheral speed if the revolving part were made 2 ft. or 18 in. in diameter. Also, larger pole space on the periphery would be obtained.

D. B. Rushmore. At one time the induction alternator was in general use in this country, especially when 133 cycles were in vogue. At 60 cycles the induction alternator easily held its own as a small high-speed machine, but became more expensive for other frequencies, and at 25 cycles could not compare with other machines. However, where high frequencies are desired it is necessary to use this form of machine.

The curve in Fig. 5 shows the increased output of the machine with the shunt condenser under somewhat the same conditions as exist in a transmission system. The critical speed is a matter of great interest and importance in many of the lines of mechanical work where, because of the type of prime mover or to obtain higher efficiency at lower cost, the tendency is to use velocities limited only by the strength of material.

C. J. Fechheimer: I wish to ask Mr. Alexanderson if the critical speed is affected by the means of support with the flexible shaft used in this alternator; that is, will self-aligning or fixed bearings materially affect the critical speed?

I also wish to ask if careful tests were made of the tensile strength of the chrome-nickel steel. Mr. Alexanderson states that the elastic limit of the steel used is about 200,000 lb. per sq. in., whereas the chrome-nickel steel furnished by the steel mills has an elastic limit of about 110,000 lb. per sq. in.

A. E. Kennelly: It is interesting that a condenser should be considered as normally attached to the machine in order to obtain normal output; although this would be a dangerous precedent if it should be considered necessary in machines of larger proportions or lower frequencies, since rotary condensers might become necessary as part of the equipment of the machine.

I wish to ask Mr. Alexanderson whether he has made measurements of any kind, to show whether a physiological effect, or shock can be felt from the machine at 100,000 cycles per second. We know that at the frequency of 2000 cycles per second a shock can be felt and that there is a certain high frequency at which a shock is not felt.

E. F. W. Alexanderson: Answering the question asked by Mr. Taylor: why the voltage of the generators decreased with increased field strength. The decrease of voltage is due to the nature of the inductor-alternator. The profile of the disc looked at from the end is indicated in Fig. 1, showing one wire in each slot of the armature. The variation of field strength in the separate armature coils is produced by the varying air-gap when a tooth is opposite or when a gap is opposite to a coil. If the excitation is driven too high, the teeth saturate and the difference between maximum and minimum induction becomes less. That is the reason why a certain field excitation gives the maximum voltage.

It is, without doubt, true that a larger diameter would materially increase the capacity. A 1-ft. diameter was selected because in building the experimental machine the item of cost had to be considered. The machine now building, which is expected to have an output of 35 kw., is designed with a diameter of 3 ft.

The resonance of the shaft, so far as I have been able to observe, has nothing to do with the alignment of the bearings. The bearings are self-aligning. Whether it would be different with a non-lined bearing, I could not tell.

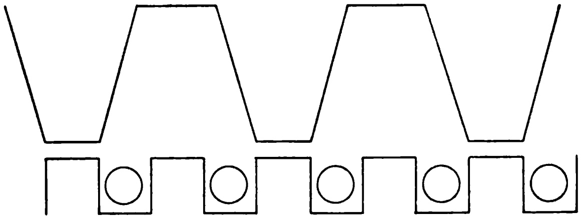

Fig. 1

In making the disc in the lathe and in the milling machine, the opinion of those who worked on it was that it is an extremely tough material. It has, therefore, been attempted and will probably work out successfully, to have the material cut before it has been tempered, because the high tensile strength of 200,000 lb. per sq. in. is not inherent in the material until it has been tempered by a special process. It is hoped it can be treated without changing the shape. The same process has been used generally in automobile gears.

Dr. Kennelly asked if it were possible to feel a 100,000-cycle shock. I can assure him that it is. I could not feel any difference between alternating current at 100,000 cycles and direct current. 100 to 150 volt at the high frequency gives the same sensation as a direct current of the same voltage.

In developing the 100,000-cycle generator one practical point was discovered which may be of interest in regard to the discussion of Dr. Kennelly's paper, as to the radiation from wires. The wire placed in the slot has a diameter of 0.016 in. It has a triple silk covering and coating of varnish. One of these wires, when placed in the slot, carries 15 amperes at a rise of 25 degrees centigrade; that is, twice as much as it will carry in the open air. Naturally the iron, which is closely in touch with the coil, takes off more heat than the air. The measurements are made by resistance, and the rise of temperature of the wire takes only a few seconds. The current density in it is about 75,000 amperes per square inch, against 2,000 to 3,000 in the ordinary machine.

DISCUSSION ON "TESTING OF TRANSFORMER STEEL." FRONTENAC, N. Y., JUNE 28, 1909

(Subject to final revision for the Transactions.)

L. T. Robinson: As the subject of iron testing has been of great interest to me for a number of years I am prompted by Dr. Lloyd's paper to ask what sort of method is this that he presents? Is it to be a standard method? Is it to be a workshop method for ordinary use, or will it necessitate the sending of samples of iron to a testing laboratory? I do not know whether there is a similarity between the methods used or not, but I believe that all users of iron have methods for testing it that have proved satisfactory. By means of one method, at any rate, with which I am quite familiar we can make an apparently satisfactory test at a labor cost of something less then 5 cents per sample.

With the advent of German activity in iron, etc., it becomes necessary to know what the results obtained in Germany mean, and we must, therefore, interpret our results by means of the Epstein apparatus. From my point of view I think it exceedingly unfortunate at this time, so long after the present methods have become well established and familiar to those most interested, that we have to consider the adoption, or the use, or the interpretation of results obtained by still another method.

Will Dr. Lloyd explain why the Epstein method is not perfectly satisfactory as a commercial standard method, and why some modification of that method, which may mean an appreciably different result, should be introduced. I believe the objections to the lack of uniform distribution of the flux in the sample are fairly well met, by the introduction, in accordance with the German specifications, of the cardboard pieces in the corners.

As to his method being accurate within one per cent, I would say that we have always been accustomed to refer our tests to ballistic measurements and from them to judge whether or not any method is a good one. Now, a question arises, is it the intention to substitute Dr. Lloyd's method for the standard method of employing a ballistic galvanometer, or does the one per cent mean that ballistic measurements have been made on these identical samples, and that the results obtained by the two methods agree within one per cent?

It seems to me that before we adopt a new method it should be demonstrated on the basis of what we have always considered to be the standard method of test, that the old method is not good and that the new one is good. Or if the new method can not be so compared, something definite should be said to convince us that what we have always considered the absolute method, namely, suitable manipulation with ballistic galvanometer, is not correct and should not be used.

V. Karapetoff: Referring to the sketch, I see the advantage over the Epstein method of assembling the strips on edge; but is not there a disadvantage in using separate corner pieces, making two joints instead of one joint as in the Epstein method? Could not a better joint be obtained by cutting the strips longer and bending them over the corner? This would do away with one of the joints, and, moreover, the joint would be made of the same material, instead of being made of a piece of iron that does not belong to the same sample.

I would also like to ask Dr. Lloyd with reference to Table XI, how he separated the hysteresis loss from the eddy-current losses? Did he assume any exponents beforehand, such as 2 for eddy currents and 1.6 for hysteresis, or did he determine the exponents experimentally from tests at different frequencies and different flux densities? As far as I am aware the values of the eddy-current loss and of the hysteresis loss are different, according to whether we assume the exponents beforehand, or determine them from the tests on the samples themselves.

C. E. Skinner: These tests have a degree of refinement rarely attempted in a commercial way, yet such refinement is necessary for the exact study of materials of this class.

After about two and one-half years use of what is essentially the Epstein method we have found it to be the most satisfactory of any that we have tried. The insertion of bent corner pieces, as described in the paper, seems to me to be unnecessary in commercial work. The added accuracy of the corner-piece method when all necessary corrections are made, is unquestionable I think, but for commercial work the accuracy with the butt joints seems to be all that is really necessary, if inductions are kept relatively low. For inductions above 10,000 the joints may be lapped as in transformer work. We use a sample three or four times as large as that used by the authors of the paper, and the sample is of such width that material, if of satisfactory quality, can be used in commercial apparatus later, so that there is little or no actual loss of material due to the relatively large sample. While the strip is not as wide as that used by the authors we can detect little or no error from shearing provided the shear is kept sharp.

The accuracy claimed for the tests by the authors is within one per cent. I do not know the accuracy of our own method but many checks lead me to believe it is within two per cent. On account of the ease and rapidity with which samples can be built and tested by our method I feel that it is to be preferred for commercial work where a large number of samples must be tested each day.

J. C. Lincoln: The first four samples *A*, *B*, *C*, and *D* have iron loss per pound given, and the annealed samples, which follow, have a very much decreased iron loss, sometimes as much as 50 or 60 per cent. I wish to inquire as to the method of annealing which gives this result.

Clayton H. Sharp: Is the wattmeter used in this test one of the ordinary commercial type, or is it something else? Is any special provision made to maintain the temperature of the iron constant, or to determine the temperature of the iron, and how is it done?

Andrew Pinkerton: In testing iron as it is received we usually want the result of a large part of one or more whole sheets and not of a small sample, as the user of the material is interested in the results from whole sheets and not from small samples. That is my main objection to Dr. Lloyd's method.

Clayton H. Sharp: Regarding a remark of the latest speaker, I would say that Dr. Epstein once remarked to me that he had found that any test of iron made on a small sample had no value whatever.

E. E. F. Creighton: Some years ago we made tests of samples of iron cut from large sheets, and found a great difference in the result, depending on what part of the sheet the sample was cut from. The gases in the furnace have a great effect on the annealing of the iron. I have no doubt also that small differences in the temperature affect the results.

M. G. Lloyd: In regard to Mr. Robinson's question of the method itself and the comparison with other methods: the method that we have developed, it is true, is not quite as rapid as some of the workshop methods already in use, and it is not intended that it will replace them. For factory purposes it is often sufficient to use a method which is perhaps not so accurate, but which will serve when simply comparative results are desired, to determine the uniformity of material, or something of that kind.

Regarding the results obtained, however, I wish to say that our aim was to develop a method that would give as high an accuracy as possible; in other words, to get what we might call absolute values, constants that would apply to the material, and would not depend upon any peculiarities of the method; for that reason we wanted wide strips and uniform flux densities, and some of the other conditions mentioned. It is true that the method described is very similar to the Epstein method, and yet it differs from it materially. At the Reichsanstalt in Germany the Epstein method was compared with several others by what was considered an absolute method, and it was found that on the whole the Epstein method gave very satisfactory results for the total loss at 50 cycles and 10,000 gausses, but that the separate losses due to hysteresis and eddy currents individually were not so close, that the one came high and the other low by three per cent, and that they very nearly balanced up in the total loss. Consequently, in making separations of that kind, as is desirable for many purposes, it is not safe to use a method which is so much in error. It is true the separation cannot be made with nearly the accuracy of the individual observations, because the result at one frequency is often in error in one direction and in the case of a second frequency it may be in the opposite direction, and the errors multiply in making the separation.

It probably would be desirable for the Institute to adopt some definite method which could be universally used and accepted by manufacturers and users of steel, in order that when tests are made they shall be under the same definite conditions, and consequently not lead to any disagreement as to quality or interpretation of results. I do not see any harm in the meantime, however, in developing in practice any number of methods, in order to have the best possible selection when any attempt is made to adopt some definite method.

As regards the comparison with the ballistic method, I do not think we can expect any alternating-current method to give results which will be the same as those given by a ballistic method. If we consider the different methods of taking ballistic curves—such as that known as the step-by-step method, by which we get a ballistic reading for each slight increment in flux, and a ballistic method in which a large change is made in flux, form the tip of the hysteresis loop to another point—it is found that the two ballistic methods will not agree between themselves; discordant results are obtained according to the process adopted in carrying out the measurements.

Similarly with alternating-current measurements, it is still an open question whether frequency affects the value of hysteresis, if everything else remains the same. Some investigations in the past have appeared to indicate large differences, as much as 30 per cent, in the value of hysteresis, due to different frequencies. When differences in conditions produce such results, and iron is put through a hysteresis loop with alternating current, it is not fair to take any ballistic measurements and say that because the alternating-current measurement did not agree with them, that the alternating-current measurement is in error. I do not think the ballistic measurement is any criterion of the accuracy of the measurements with alternating magnetization.

The error in our method has been determined simply through a consideration of the separate sources of error and the accuracy of the instruments, and by a comparison of measurements under slight variation of conditions. When I state the accuracy as one per cent, I consider that the results, before the separation of losses, are to be depended on, that is, the constants of the material are known to that degree of accuracy.

Professor Karapetoff's comments on the joints in the corners are partly answered in the paper itself, in the part which I did not take time to dwell upon. Ordinarily, the corner pieces are of the same material as the test pieces, but we have found it is not necessary that they should be. One can get sufficiently good results for all commercial purposes by using stock corner pieces, instead of making a set of corner pieces for each specimen, and for that reason, in practice, we use them very often in that way.

The objection to the second joint does not seem to be justified by the results, because we find the difference in flux between the center and the end of the test piece to be very small indeed, and consequently any objection to the two joints at the corner is not substantiated.

The exponents have not been assumed in any case, as was intimated. The exponents are determined by obtaining values for hysteresis or eddy currents at two different flux densities, consequently derived from entirely independent measurements. The values of these two losses at any one flux density are determined by runs at two frequencies. Two observations at one flux density determine the separation of hysteresis and eddy-current losses. Then the values taken at two different densities are sufficient to determine the exponent which applies to these two particular flux densities.

In regard to the question on annealing, I may say that we have not done much of that. The specimens we have tested have in almost all cases been tested in the condition in which we received them, and the question of annealing was a question of past history with us.

Dr. Sharp's question in regard to wattmeter and temperature conditions is answered in full in the paper.

As to the quantity of material, discussed by several, that is a point on which every person, I take it, must have his own opinion. Some think that the results of tests on samples are not of any value, and the test must be made on the entire material under question, and others seem to have found it satisfactory to use small test specimens. My own opinion is, that once a sufficient quantity is selected to represent a fair average of the material, if the method demands more beyond that, it is an undesirable feature of the method. The Epstein method, as usually employed, requires 10 kg. or 22 lb. of iron. What I take to be slightly better results are obtained with as small a quantity as 4 lb., and I think that is an advantage. Of course, if a person wants to test a whole sheet or larger quantities, it is easy to adapt the apparatus to the larger quantity. The question has been to find the apparatus which can be adapted to smaller quantities. With a method available for small quantities, one can always adapt it to one's own needs for large quantities.

I think I may be permitted at this time to call attention to the magnetization curves in Fig. 5. showing the wattless component of exciting current plotted against flux density for silicon-steel and ordinary steel. At low flux densities the silicon-steel is more highly permeable than the other, whereas at higher flux densities it is less so.

In regard to the effect of the higher magnetizing current, I wish to say one thing. It is of course undesirable for some reasons to allow the exciting current to run too high, and that has limited the design of transformers with this silicon-steel in one direction, that of pushing the flux density too high. It has been very generally thought, however, that the regulation of the transformer would be affected by a high magnetizing current. I wish to speak of that, because it is an error which is commonly made. Most of the formulas which we see in print for the regulation of the transformer involve magnetizing current. As a matter of fact, magnetizing current has nothing whatever to do with regulation, and any objections to high magnetizing current in transformers are not along the line of inferior regulation. The reason for that is, there is a certain voltage drop in the transformer, due to magnetizing current, but it comes in both at no load and at full load, and it can be easily shown that it does not affect the regulation.

DISCUSSION ON "THE CONVECTION OF HEAT FROM SMALL COPPER WIRES." FRONTENAC, N. Y., JUNE 28, 1909

(*Subject to final revision for the Transactions.*)

V. Karapetoff: Dr. Kennelly uses the absolute electromagnetic system of units, and besides, he uses the abbreviation "abs." for absolute. I have always thought that this system of notation is very convenient, as well as the notation "*abstat*" for absolute electrostatic units. But, while fully appreciating the convenience of the use of the absolute system in some cases, I would like to ask Dr. Kennelly the reason for using this system in this paper? For instance, referring to Table I or to any other table in the paper, it will be seen that the current values could just as well have been expressed in ordinary amperes, because they come very distinctly within the range of amperes. In the same way, Dr. Kennelly measures resistance in absohms, or absolute ohms, then multiplies by 10^{-9}, and finally gets ordinary ohms.

I would also like to ask what was the reason for introducing such unfamiliar units as megabars for pressures, when they could have been expressed in atmospheres, or, to be more consistent, in metric atmospheres (one metric atmosphere is one kilogram pressure per square centimeter). I see that power could not be expressed conveniently in watts in this case, but I do not see why abswatts or absolute watts could not be employed, or, still better, milliwatts or microwatts, which every electrical engineer would understand.

Dr. Kennelly calls formulas (8) and (9) *exponential*. I think it more correct to call them *parabolic*. What is known as an exponential expression is of the form $y = Ce^{\mp x}$; there are several phenomena in physics and in engineering that follow this exponential law. The expression used in the paper is of the form $y = Cx^n$, and it would be more consistent to call it a parabolic law. However, this is a minor point, provided the distinction be clearly understood.

Formula (28) is rather a common form of a law that is met with in engineering; that is to say, where one variable varies as a certain power of another variable, and then there is a correction term, in this case = 25 (correction for free radiation). If it were not for the correction term, the coefficients of the formula could be easily evaluated from the results of experiments, using logarithmic paper. I would ask Dr. Kennelly if there is any method by means of which formulas (28) and (29), that is those containing a correction term, could also be handled by means of logarithmic paper; or do we have to go back to the laborious method of least squares?

Charles P. Steinmetz: I have given considerable attention to the study of a rational reduction of empirical phenomena and have also found the feature mentioned by Professor Karapetoff, the existence of a constant term, a great annoyance when using logarithms to derive a parabolic law. But I have found that with a little experience the method can still be used. If the logarithmic line is curved slightly, concave or convex, it signifies a positive or negative constant term. Subtracting, or adding a constant term to the function, and replotting, produces a second logarithmic curve. If this has the same curvature, it indicates that the constant term is too small; if it has the opposite curvature, by interpolating between the two logarithmic curves there results a value of the constant term which gives minimum curvature. Where necessary, by a second interpolation, a still closer approximation can be obtained, thereby evaluating a parabolic function with constant terms. This appears to me the simplest method. If any one knows of a simpler method I shall be glad to hear of it, because the quick evaluation of empirical curves is frequently of great importance.

Chas. F. Scott: I would reinforce what has been said about the nomenclature in this paper. The facts set forth are engineering facts, which should be known and appreciated and understood by ordinary engineers as well as by scientists. I am inclined to think that some people who may want to use this paper would be apt to interpret " abs " as meaning absurd. Dr. Kennelly himself, in presenting the paper, in order that those present may have some conception of what he is talking about, says in one place " that is approximately equal to one atmosphere " The term " megabar " conveys very little information to the average engineer, and other strange names are equally perplexing.

Appearances to the contrary, the paper is not abstruse nor does it deal with the mysterious. It deals with phenomena which are matters of ordinary experience and for which there is an adequate, everyday language. Without questioning the excellence of the absolute system of units, I fail to see its utility in the present case. Even if it were conceded useful to call an ampere or a watt by some other name, why should we mystify the barometric pressure by some unfamiliar term that means nothing to most of us? So far as I see there is no fundamental relation in these tests requiring absolute units to express the watts of the atmospheric pressure—the latter is simply recorded as a condition under which the tests are made and its value does not enter into any formula any more than does the serial number of the test.

Another point, if I understand correctly, Dr. Kennelly points out in the main test, that the curves showing the relation between convection and wind velocity cannot be drawn down to zero, they would tend to show zero as convection of heat at zero speed although there is, of course, a considerable loss. Now the speed that is really involved is not the absolute speed of the wire, but the relative speed between the wire and the air. When the wire is stationary, there really is some breeze created by the natural rise of air passing the wire. The natural draft caused by the rise of the hot air when the wire is actually stationary in regard to surrounding objects, may result in an actual velocity with respect to the air which possibly accounts for the apparent discrepancy. Possibly we could get the zero point; that is, the zero of relative motion between wire and air, by raising the wire at a definite speed so that the wire is continuously surrounded by the same air.

Paul M. Lincoln: I would like to express my appreciation of the data which Dr. Kennelly has presented in this paper. The engineer who is designing electrical apparatus is confronted at once with the questions: 1. How much heat can be radiated from the surface of this apparatus with a given temperature? and 2. How is the law of radiation changed by forced ventilation? The data which Dr. Kennelly has presented here give the best answer to those questions that I know of.

In this paper Dr. Kennelly gives data as to the rate at which heat is dissipated from bare metallic surfaces. The designing engineer is particularly interested in the rate at which insulated surfaces will dissipate heat. A study of the changes, if any, which will be introduced into the values determined by Dr. Kennelly by covering bare surfaces with the ordinary types of insulation would be of great assistance to the designing engineer. I hope that he will give us the result of such study at some future meeting.

A. E. Kennelly: In regard to the matter of "abs" and "abwatts", an apology is offered for the names, which are slang, but I offer no apology for using the C. G. S. system. Our reason for using the C. G. S. system in this case is that we have to deal with certain fundamental physical effects. This is a physical paper, rather than an electrical engineering paper. This report is only a first step towards electrical engineering.

It is true that we actually used ammeters, worked with amperes, and put them back into absamperes, in the manner Professor Karapetoff pointed out. We thought it simpler to keep to one and the same system of units, and not to oscillate between practical and absolute units. We may have been wrong in taking the absolute system as our choice, but having once adopted it, I think we were right in adhering to it.

I think Professor Karapetoff is right as to the term "parabolic" We should have said parabolic instead of exponential. We should have been glad to adopt that amendment in terminology.

In regard to what Mr. Scott has pointed out, the reason we chose the *megabar* is because it is the C. G. S. unit of pressure, one megadyne per square centimeter. If we are going to use C. G. S. units at all, we must use them throughout in order to be consistent. I do not think we should have gained in simplicity of statement if we had tried to define an atmosphere with equal precision in the ordinary system.

The remarks of Mr. Scott in regard to the matter of the virtual velocity of free convection are very pertinent and seem likely to be correct, but we did not dare to say that. We do not know that the velocity of the air past the wire was twenty-five centimeters per second. The formula which we give to include the virtual velocity of free convection is an empirical formula, but we hope it may be possible to demonstrate that the formula is rational, as Mr. Scott suggests.

DISCUSSION ON "EVEN HARMONICS IN ALTERNATING-CURRENT CIRCUITS." FRONTENAC, N. Y., JUNE 29, 1909

(Subject to final revision for the Transactions.)

Frederick Bedell: Confirming the author's conclusions, I have found that a direct current in a transformer increases the iron losses very much less than might be supposed, and also increases the copper losses very much less than might be supposed. The increase in the copper losses is due to two causes: 1. The increase of the exciting component of the alternating current, which is in quadrature with the power component and so increases the total alternating current by a very small amount. 2. The direct current itself. So far as heating effect is concerned, the direct current behaves as if it were in quadrature with both the power component and the exciting component of the alternating current—the three quantities being mutually in quadrature as though in three dimensions—so that the direct current increases the effective value of the whole current very little. For example, 20 per cent direct current superposed upon an alternating current increases its effective value only 2 per cent.

V. Karapetoff: On the first page of his paper Mr. Taylor refers to certain statements usually made in text-books. He says that there is a common misconception to the effect that even harmonics could not be present in commercial circuits, because otherwise the alternating-current wave would have a direct-current component; this component could in some way be utilized, and thus we would have direct current without the use of commutating devices. I think the whole subject of even harmonics can be understood with reference to the following two simple statements:

1. Let a conductor revolve in an unsymmetrical field, such as is represented in Fig 2, the poles being of different size.

The electromotive force induced at any instant is proportional to the rate at which the flux is cut, or

$$e = \frac{d\phi}{dt}.$$

Integrating this, gives

$$\phi_1 = \int_0^{t_1} e\,dt,$$

where ϕ_1 is the total flux issuing, say, from the north pole, and t_1 the interval of time during which the conductor cuts the lines of force under this pole. Similarly, for the south pole

$$\phi_2 = \int_{t_1}^{t_2} e\,dt.$$

But ϕ_1 is always equal to ϕ_2; this is a fundamental law of nature: It is impossible to have a north flux larger or smaller than the corresponding south flux. Hence

$$\int_0^{t_1} e\,d\,t = \int_{t_1}^{t_2} e\,d\,t.$$

With reference to the curve shown in Fig. 2, the above equation means that the area of the curve above the axis of abscissas is always equal to that below the axis, however unsymmetrical the curve itself might be. In practical terms, a direct-current measuring instrument, consisting of a permanent magnet and a moving coil, always shows zero in this case. Therefore, in whichever way the machine is constructed, direct current cannot be obtained from it without the use of a commutator or an electrical valve. (Who of us in our younger years did not attempt to invent a direct-current generator without a commutator!) The above simple equation or rather the fundamental law $\phi_1 = \phi_2$ shows why this is impossible.

2. When more than one conductor is connected in series, the conductors must be spaced unsymmetrically in order to preserve even harmonics, provided such harmonics are induced in each individual conductor. Indeed, with reference to the curve in Fig. 2, let two conductors, in which such electromotive forces are induced, be spaced by 180 electrical degrees and connected in series. To find the resultant electromotive force a second curve must be drawn, inverted, and shifted through 180°. It will be easily seen that the resultant curve has identical half-waves, and all the even harmonics are cancelled. But if the shift is different from 180°, some of the even harmonics can be preserved.

Since in practice armature conductors are spaced symmetrically, the statement remains true that no even harmonics are present in ordinary commercial circuits.

By suitably spacing the conductors, odd harmonics may be cancelled, instead of even ones. Thus, by shifting conductors through 120° and connecting them in series, the third harmonic is abolished, while the second, fourth, etc., are preserved to some extent, provided they are induced by an unsymmetrical field in each individual conductor.

Chas. F. Scott: Some years ago when synchronous converters were first used with a middle wire, in the way familiar to all, the two-phase converter was employed and the middle point was brought out from the middle of the transformer winding which served as a balance coil. That was a simple matter. When the problem came to use star-connected coils on three-phase circuits, it seemed at first that a peculiar and unbalanced condition, would result and the direct current would magnetize the cores independently and the neutral point might go floating about in some peculiar way, the transformers probably behaving quite badly. We were surprised on making a test to find how well the apparatus did behave, although the alternating-current transformers were treated with large amounts of the direct current. In such cases, however, the magnetizing current is in general small compared with the normal current, hence a large magnetizing current may not greatly increase the total current. In other cases, however, this direct current may lead to disturbances which are considerable. In one case with which I had to do some time ago, involving transformers which had little or no output, but were depended on for their voltage relations, it happened that there was considerable resistance in the primary circuit, but this ordinarily had but little effect as the flow of magnetizing current was very small. When, however, direct current flowed in the secondary circuit, then the magnetizing current was increased many times, which caused an undue drop in the primary resistance, and did affect the operation of the apparatus.

The curve shown in Fig. 5 is of interest, as it shows the peculiar form of the magnetizing current which has to do double the duty of counteracting the direct current and of producing its own magnetization.

Charles P. Steinmetz: Regarding the statement of the author, confirmed by Dr. Bedell, that the iron loss in the unsymmetrical cycle produced by the existence of second harmonics resulting from direct current, is not seriously increased. I made some investigations on the subject 18 years ago, which were published in the A.I.E.E. PROCEEDINGS of 1892, in the second paper on the law of hysteresis. There the conclusions are that at the same difference between the limits of flux density, the hysteresis loss is the same regardless as to whether the cycles are symmetrical of between unsymmetrical limits. There would thus be no increase in iron losses. The unsymmetrical cycles, which I investigated, were relatively small, and the accuracy not so great. There may have been smaller differences which would have escaped notice, but they certainly prove that there is no serious increase of hysteresis loss in the unsymmetrical cycle over the symmetrical cycle, with the same distance between the limits of flux density. The eddy-current loss, however, is probably increased by the greater abruptness of the change.

It is also interesting to realize that even harmonics are practically as frequent as odd harmonics in the transient phenomena of alternating-current circuits.

As to the discussion of the origin of even harmonics, the usual statement that they cannot exist is misleading. The correct statement is that the *constant term*, which is the first term of even harmonics, cannot exist in a machine without commutating or rectifying devices, whether symmetrical or unsymmetrical arrangements are used; but the further terms of the even harmonics, from the second upward, can exist; there is no physical reason why they should not exist, but due to constructive conditions, they are practically always absent.

J. B. Taylor: I do not think there is anything to rebut in the discussion. Professor Karapetoff possibly misunderstood a reference to the text-books. The books themselves are not in error, but hazy ideas of even harmonics exist in the minds of many engineers, and the treatment in the text-books has been rather meagre, which possibly accounts for the misconceptions.

DISCUSSION ON "CALCULATION OF IRON LOSSES IN DYNAMO ELECTRIC MACHINERY." FRONTENAC, N. Y., JUNE 30, 1909.

(Subject to final revision for the Transactions.)

R. E. Hellmund: Mr. Hanssen says that the teeth of dynamo electric machines are subject to a rotary magnetization by reason of leakage. Though some of the leakage fluxes actually pass the teeth crosswise, the leakages are so small compared with the main flux that the statement does not seem quite justified. This, of course, is not of great importance. In designing induction motors I have found Mr. Hanssen's method to be most useful. Other methods given for calculating surface losses are either too complicated to be of practical use or the results obtained by them are too inexact. Mr. Hanssen's method represents a very good compromise between exact theory and purely empirical formulas. It is, of course, not to be expected that any method for calculating core losses will always give correct results, it being well known that machines of the same type manufactured at the same time show core losses differing from each other as much as 20 per cent, sometimes even more. I have found, however, that the results obtained by Mr. Hanssen's method have always come close to the average value of the tests on a number of machines of the same type.

A. E. Averett: There are certain features of this paper which seems to me to be more of a specific than a general feature. In one part of the paper certain corrections should I think be applied to a specific type of machine. As soon as the type is changed or the proportion of the iron in the teeth and in the yokes, the corrections will have to be changed.

Near the end of the paper it is said that a slight cut in the lathe will increase the core-loss about 50 per cent. I think that point is open to question. I have seen machines in which the rotors have been turned and in which the core-losses have not been increased appreciably; that is, with any commercial test the difference could not be detected. Again, I have seen machines where the core-loss has been nearly doubled. I think if the rotor is properly turned it will very seldom increase the core-loss appreciably.

In the high-frequency machines, silicon-steel decreases the core-loss very much; for this reason I think it advisable to use it in spite of its increased cost.

V. Karapetoff: In estimating iron losses in revolving machinery it is not safe to rely upon the results obtained with stationary samples, because the distribution of the flux is far too irregular in space as well as in time. The safest procedure is to determine the actual iron loss from tests on a large number of actually built machines, at various densities and frequencies, and then use these data. In doing so, it will be found that the expression: total iron loss $= a\,B + b\,B^2 + c\,B^3$ comes much closer to the experimental curves than the formula $\eta\,B^n$. Here B is flux density, and a, b, c, are empirical coefficients.

In regard to Figs. 1 to 9 given in Mr. Hanssen's paper: These are not photographs of actual lines of force, but of some fluid flowing between two plates of glass. Into this fluid some coloring matter is injected, and then the apparatus is projected by means of a lantern or photographed. To my knowledge, the method was first used by Professor Hele-Shaw. The only difference between the assumed distribution of magnetism and the flow of the water between two parallel plates of glass is that water has inertia while the magnetic lines are devoid of inertia. By making the water flow very slowly the effect of inertia is practically eliminated, and in order to make the analogy complete paths are provided whose mechanical resistances to flow are in the same ratio as the magnetic reluctances of the air-gap and the iron teeth.

The streaks seen on Figs. 1 to 9 represent the actual directions of the streams of water. The light streaks between the poles are not assumed or anticipated, but show that, while the reluctance there is high, nevertheless some water prefers to flow into the narrow space between the poles, instead of going around through the armature. This illustrates magnetic leakage between the poles.

DISCUSSION ON "A SKETCH OF THE THEORY OF THE ADJUSTABLE-SPEED, SINGLE-PHASE, SHUNT INDUCTION MOTOR," AND "REPULSION MOTOR WITH VARIABLE-SPEED, SHUNT CHARACTERISTICS." FRONTENAC, N. Y., JUNE 28, 1909.

(Subject to final revision for the Transactions.)

V. Karapetoff: I would like to ask Mr. Creedy the reason for calling this motor an induction motor? It seems to me that it would cause some confusion in our nomenclature. An induction motor, according to present nomenclature, is a motor without a commutator. I think that the title of the paper should be "A Sketch of the Theory of the Adjustable-Speed, Single-Phase, Shunt, Commutator Motor."

E. F. Alexanderson: The paper by Mr. Creedy on the shunt induction motor treats of the same subject as my paper on the shunt repulsion motor and the difference in the subject matter appears to be only the name. Mr. Creedy's paper therefore affords an excellent opportunity for comparing the viewpoint of similar investigations carried on independently.

In regard to the technical definition of certain terms used in both papers, it may be pointed out that the terms "adjustable speed motor" and "shunt motor" are used to signify a motor with the characteristics of a direct-current shunt motor with field control. It is possible to obtain variation in speed by methods which do not give shunt characteristics. For instance, the speed of the ordinary induction motor can be varied by introducing resistance in the secondary winding. In certain cases the introduction of reactance will give the same results. A speed variation obtained in this way is similar to the speed variation of a series motor. Motors of various makes using this type of speed variation have been in the market for some time in Europe as well as in America.

The speed variation by introduction of resistance in the secondary has been used to some extent in the American built Milch motor in cases where speed variation by this method is applicable. The motor which Mr. Creedy refers to as being the only motor of a similar type built in this country, is apparently the motor which I dealt with particularly in investigating the possibilities of an adjustable-speed shunt motor. This motor has been on the market for several years and is known as the Milch motor. It is classified as a repulsion induction motor. The diagram in Fig. 21 of Mr. Creedy's paper illustrates this type.

In my paper it has not been attempted to describe early types of motors or to mention names of inventors, because so many have been working along the same lines that it is difficult to give credit to some without doing injustice to others. My investigation has been based on the assumption that the system for compensating the power-factor developed by Milch is essential for the success of any motors of this class. This conclusion Mr. Creedy has also reached and a direct statement to that effect is made in his paper. The object of my paper is simply to give the results of an investigation as to what practical additions can be made to the constant-speed motor developed by Milch in order to introduce the adjustable-speed feature.

For this purpose not only the theoretical possibilities but also the established practice in manufacturing had to be considered. The aim has been to develop such a method of control that the constant-speed, repulsion, induction motor of a well-known make could be used for adjustable-speed work with the least amount of modification. In the first attempts it appeared as if speed variation by field control, illustrated in Fig. 6 in my paper and in Fig. 4 of Mr. Creedy's paper, would be the most applicable.

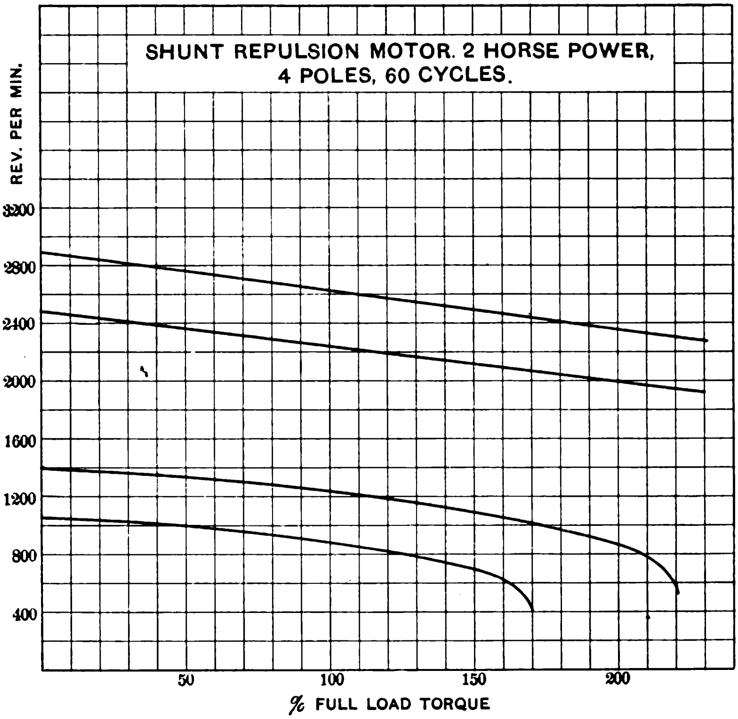

FIG. 1

The experimental data obtained from a test of the 30-h.p., 25-cycle motor built for experimental purposes, were worked out with reference to field control. The results are shown in Figs. 4 and 5. Subsequently, a 3-h.p., 60-cycle motor was built, adhering as closely as possible to the manufacturing methods developed for the constant-speed motor. In designing this motor it appeared that a motor of the original type could always be furnished by adjustable-speed field control, provided the motor was of the reversing type; in other words, provided it had a section of the field winding placed in quarter-phase relation to the main part of the winding. The method of speed variation with armature control was also reconsidered, and it was found that a suitable arrangement of the controlling circuit made it possible to apply a practical system of speed variation to the original type of motor which is being built at present for constant speed. The speed variation can be applied to the non-reversible as well as the reversible type without any modification of the motor itself. By this method it is practicable to lower the speed to one-half synchronous speed, and increase it to 50 per cent above synchronous speed.

The exact characteristic curves and diagrams for this combination were not available for publication at the time the paper was printed, and for this reason it was only possible to state that it is feasible to obtain a speed variation of three to one with armature control. In view of these results, I feel that exception should be taken to the statement in Mr. Creedy's paper that there is no thoroughly practical method of lowering the speed, although there are several good methods for raising it.

In controlling the speed by armature regulation in the way mentioned, the commutation appears to be nearly as good for all the sub-synchronous speeds down to one-half synchronism as it is at synchronous speed. At over-synchronous speeds, the commutation remains good up to about 30 per cent above synchronous speed, whereas at 50 per cent above the synchronous speed the sparking becomes objectionable. The tests referred to were made on 3-h.p. and 2-h.p., 4-pole, 60-cycle repulsion induction motors of standard make, and the speed was varied from 2700 to 900 rev. per min.

In answer to Mr. Creedy's expectation that an adjustable-speed shunt motor would soon be placed on the market in either Europe or America or both, it can be said that the latest developments show that such a motor is already on the market; but this fact was not known and the motor has been considered as a constant-speed motor, due to the lack of a suitable controlling device. Owners of such motors may be interested to know that it will be possible to add such a controlling device for adjustable speed to their equipments as soon as such a device has been developed.

My paper did not intend to cover all the possible connections. The investigation I made was for certain practical purposes, in conjunction with established practice of manufacture, and therefore it might not be of sufficient interest at the present time to go into detail in answering questions relating to the different connections that may be suggested.

DISCUSSION ON "MULTISPEED INDUCTION MOTORS."
FRONTENAC, N. Y., JUNE 28, 1909

(*Subject to final revision for the Transactions.*)

H. C. Specht: It is well known that the induction motor is the simplest motor to build and operate. It can be used with advantage for a variety of purposes, especially for constant-speed service. Where variable speeds are required, however, the induction motor is put at a disadvantage by the direct-current motor.

A great many methods for varying the speed of the induction motor have been employed. Some of these methods are discussed by Messrs. Reist and Maxwell, but treat chiefly of motors in concatenation and with multispeed apparatus consisting of a single motor. For a two-speed motor consisting of a single winding, and with a speed ratio other than 2:1, the authors say that 33 leads are required for a three-phase winding. It would be of interest to know whether this applies to any speed ratio other than 2:1 and to any number of poles, or what particular combination of two-speed connections the authors had in mind. For various schemes of connections the number of leads is generally dependent on the number of poles and the type of winding.

The authors give a table of approximate maximum outputs for the different combinations of series and multiple, star and delta, connections of a two-speed motor with a ratio of 2:1. I assume from the maximum output figures that the coils of the windings have a throw closer to the pitch of the double number of poles. This table would be of greater value if the current, the necessary amount of copper and iron, and the size of the mechanical parts were compared with some standard.

The maximum output depends on the limited density in the copper and iron, and the stresses in the mechanical parts. It is, therefore, clear that some of the outputs given in the table cannot be met without increasing or wasting some material.

The authors say if the speed corresponding to the difference in the number of poles is higher than the synchronous speed of the first motor, the set will not accelerate by itself to this speed. This statement would be correct if the first motor, which has the greater number of poles, is connected to the line, If the synchronous speed of the second motor is higher than that of the differential concatenation, then the second motor, instead of the first motor, may be connected to the line. In the case where neither of the two motors has a higher synchronous speed than that of the differential concatenation, the speed for the latter cannot be obtained without auxiliary means.

In regard to a cascade set consisting of two two-speed motors each one having pole ratio of 2:1. I know that 12 different speeds can be obtained. For example, the first motor having 10 and 20 poles and the second motor 2 and 4 poles, speeds corresponding to the following number of poles can be obtained: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24. In case only one of the two motors is a two-speed motor, the maximum number of speeds is 7.

It may be well to mention, however, that the different speed combinations are not practicable in every case. Furthermore, sometimes it might not be possible to obtain the exact speeds for every one of the different connections. In such cases the two motors may be interconnected mechanically by means of gears, chains, etc. having a speed-ratio which will give the desired speeds. It is clear, then, that practically any possible combination of speeds can be obtained with a cascade set; whereas with multispeed motors consisting of a single motor, such variations in the number of speeds cannot be obtained.

The authors say that the number of speeds obtained by a cascade set is limited by the centrifugal stresses in the larger motor. This limitation is, however, much less than on a single multispeed motor for the same speeds. The individual motors of a cascade set can be designed so as to have greater width and smaller diameter, thus keeping the peripheral speed lower than would be the case with a single motor.

The electrical performances of a cascade set depend entirely on the design of the individual motors. The curves given by the writers have reference to a particular design only.

There is no doubt that the motors for concatenation are very simple and safe in regard to control and operation. Even though the cost of a cascade set is rather high, it can be recommended in various cases, especially where simplicity and safety of control and operation are of great importance. The application of one or the other method of the various multispeed motors depends on so many conditions that a general rule as to which method should be used can hardly be given.

A. M. Dudley: I would like to call attention to another method that has been used for getting multispeeds. Quite a little has been done with it in England. I refer to the so-called method of internal concatenation. This is accomplished by winding the stator and also the rotor of a motor of normal mechanical structure for two sets of poles. If the line current is led into one of the stator windings, the other being short-circuited, and the two rotor windings are connected in series, the motor will run with a synchronous speed corresponding to the sum of the two pole numbers for which the motor is wound. Resistance may then be inserted in the remaining stator winding for varying the speed, as in the case of a normal wound secondary motor. For example, if the stator is wound for 4 and 6 poles, and the rotor also, it is possible by means of such a connection, using a single magnetic and also a single electric circuit, to have a speed corresponding to 10 poles.*

Charles P. Steinmetz: There are two methods of getting different speeds from the induction motor. One is by changing the number of poles, the other by concatenation or cascade connection. Anyone that has designed an induction motor realizes that the difficulty in getting good motor constants is to give sufficient peripheral speed without increasing excessively the size of the motor. A large pitch per pole; that is, many ampere-turns per pole, is necessary to get a reasonable exciting current and reasonable leakage flux. Changing the number of poles; for instance, doubling them to get half-speed, reduces the pole-pitch one-half. The motor constants are thereby made twice as bad. That is the disadvantage of changing the number of poles. It means that this type of multispeed motor is more difficult to design for low-speed operation. A motor well designed for the low speed, produces an excellent machine for high-speed operation; but in any case the motor has to be more carefully designed than would be demanded by a motor intended merely for high-speed service. Unfortunately, concatenation does not overcome this difficulty; for in this case the second motor is fed from the first motor. While the motor always keeps the same number of poles, and thereby the full pole-pitch, the first motor carries not only its own, but also the second motor's exciting current; and its leakage reactance is the sum of the leakage reactances of both motors, as the second motor is an inductive load on the secondary of the first motor. Thus concatenation doubles the exciting current and the self-inductive impedance, making the constants of the motor twice as poor, just as is the case when doubling the number of poles in one motor. In short, the electrical characteristics of the concatenated couple of motors are the same as the electrical characteristics of one motor with a changeable number of poles.

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* See article by Dunn, *Journal of the Institution of Electrical Engineers*, September, 1907.

That brings us to the question of the relative characteristics of the two types of motors. I have been interested in the subject for many years, but have been forced to the conclusion that, in general nothing is gained by concatenation over the method of changing the number of poles in a single motor; but something is lost by having two structures instead of a single structure. Concatenation is therefore applicable only to special purposes, as in the case of railway motors. For general stationary work, the motor with a changeable number of poles is generally preferable.

H. C. Specht: In regard to the statement made by Dr. Steinmetz that the rotor of the motors in a cascade set has to be greater in diameter, thus necessitating a higher peripheral speed. This is a question of design. If the motors of a cascade set are properly designed, the diameters can be kept smaller than on single multispeed motors. Consider, for example, a cascade set of which one motor has 12 poles and the other motor 4 poles, and speeds corresponding to 12 and 16 poles are required. In this case the motor with the 12 poles be designed with a leakage, almost equal to that of an ordinary single-speed motor. Then the motor with 4 poles would have to be designed with very small leakage, so that the total leakage of the set would be very little increased over that of the 12-pole motor. With such a design it is clear that the 12-pole as well as the 4-pole motor could be designed with a smaller diameter than a two-speed motor having a 12-and 16-pole winding.

Charles P. Steinmetz: It is entirely correct that a 4-pole motor can be designed with much smaller leakage flux than a 16-pole motor; and concatenated to the latter, the former would be less liable to spoil the constants of the couple than if it also had 16 poles. But the same applies to changing the number of poles: changing from 16 to 20 poles would spoil the motor constants less than doubling the number of poles. The two methods, concatenating two motors, or changing the number of poles of one motor, still give essentially the same change of motor constants with changes of speed.

E. F. Alexanderson (by letter): One of the speakers referred to the method of speed variation by means of internal concatenation, and to an article published on this subject in 1907. I designed a motor of this kind in 1904. This experimental machine was built with the object of testing the internal concatenation as well as the connection of the same machine as a frequency-changer from 25 to 60 cycles. At the same time tests were obtained on a motor with two sets of windings; in other words, a motor which combined a four-pole and a six-pole winding on the same structure.

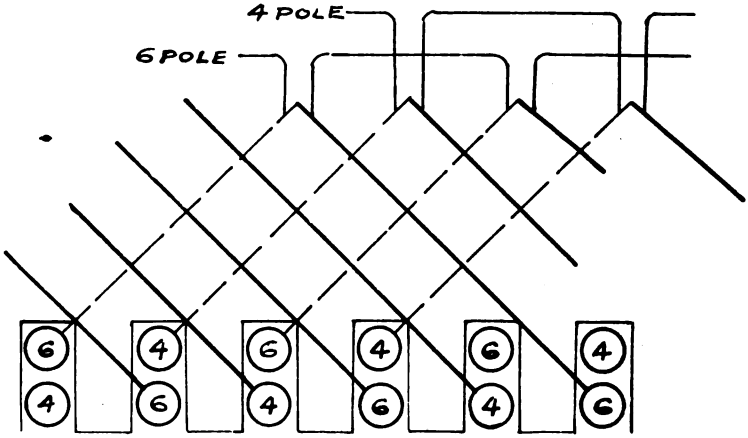

Fig. 1

The field as well as the armature of this motor was made from the windings of a standard six-pole motor without changing anything but the connection of the coils. To my knowledge this was the first machine built with a double set of windings without introducing any special feature in the arrangement of the coils. Fig. 1 shows that each slot contains one member of the six-pole and one member of the four-pole winding, and that the two windings alternate in the upper and the lower positions of the slot. The test confirmed the theory and demonstrated that the two windings were electrically independent and operated in the same way as if wound on separate cores connected to the same shaft. The machine could therefore be used as a concatenated set of motors or as a frequency-changer, in accordance with well known methods. In the case of internal concatenation the collector rings were not used.

An interesting feature which was specially studied was the magnetic combination of the two fluxes. It had been foreseen in the design of the machine that two fluxes would combine in a resulting flux with an unbalanced distribution so as to cause a one-sided attraction of the armature, and a special reinforcement had been provided in the armature in order to avoid mechanical resonance. The test demonstrated, however, that no reinforcement could be applied to the shafts and bearings that would reduce the vibration sufficiently to make the machine commercially operative. This objection would of course be overcome if the number of poles were doubled, or in any combination where the difference in the number of poles is four or more, in which case the magnetic attraction would be balanced.

Endeavors were made after the test described to find a commercial application of the internal concatenation. However, it is difficult to find a justified application for ordinary concatenation and still more so for internal concatenation where a limitation is imposed on the relative number of poles. Although for the reasons mentioned the experiment did not give much encouragement to the use of internal concatenation, it proved of value as demonstrating a simplified method of winding a four-pole and a six-pole winding on the same core. At the same time experiments were made to obtain a continuous variation of speeds by controlling the four-pole and the six-pole windings simultaneously. The scheme proved perfectly feasible, although of course it gave a low efficiency. The most practical combination after all which was tried was simply a squirrel-cage rotor and a switch for changing the four-pole winding into an eight pole by the well known Dahlander-Lindstrom connection. In this way a good three-speed motor was produced with four, six, and eight poles.

A. E. Averett: In the concatenated motor the speed reduces somewhat in this way: with the collector-ring single-speed motor the reduction in speed is accomplished by reduction in efficiency, the power-factor remaining constant. In the concatenated motor the efficiency will remain approximately constant, but the power-factor goes down as the speed is decreased. The power-factor on the line is therefore high with secondary resistance, as against low power-factor where the speed reduction is gained by concatenation.

H. G. Reist: The 33 leads mentioned are for a motor of the first class and will include any ratio of speed if the windings are Y-connected.

Discussion on "The Heating of Induction Motors."
Frontenac, N. Y., June 28, 1909

(*Subject to final revision for the Transactions.*)

R. E. Hellmund (by letter): In calling attention to the large losses in the motor while the motor is starting, Mr. Gray is apt to give the squirrel-cage motor a worse reputation than it merits. It is true that the losses at the moment of starting are very large, but it is also true that these losses decrease rapidly as soon as the motor is under way. I believe that the squirrel-cage motor can sometimes be used under pretty serious starting conditions where a wound secondary motor would be objectionable, as the amount of the starting losses at the first moment proves by no means a serious obstacle. In considering a proposal involving rather severe starting conditions, I proceeded as follows:

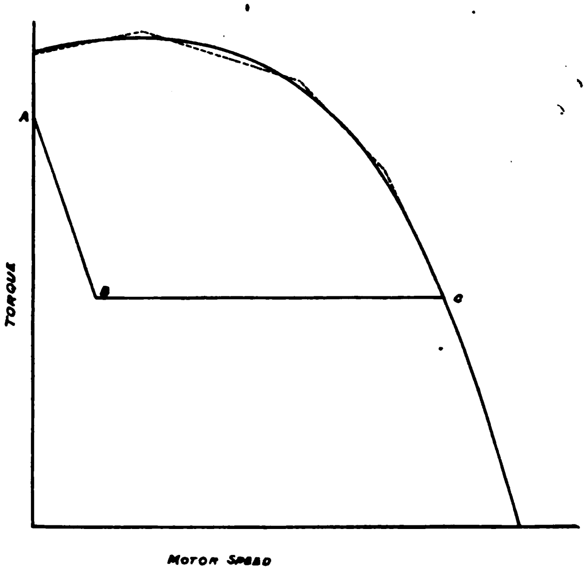

Fig. 1—Speed-torque curve

The speed-torque curve of any motor can be replaced approximately by a number of straight lines, as shown in Fig. 1. From the total torque, the load torque, represented by the straight line *B C*, should be subtracted. Also a liberal allowance for the friction of rest should be made for the first part of the starting period, as indicated by the line *A B*. By subtracting the load and friction torque from the total torque, we obtain the curve of the torque available for acceleration, as shown in Fig. 2.

For each of the straight line parts, the following relations apply, see Fig. 3. The equation for any of the lines is

$$T = T_1 + \frac{T_2 - T_1}{v_2} v \qquad (1)$$

We know further

$$d v = p\, d t \qquad (2)$$

where $d v$ is the change of speed during the time $d t$ and p is the acceleration, we find

$$p = \frac{T}{m} = \frac{T g}{w} \quad .$$

where

m = mass to be accelerated.
w = weight " "
g = acceleration of gravity.

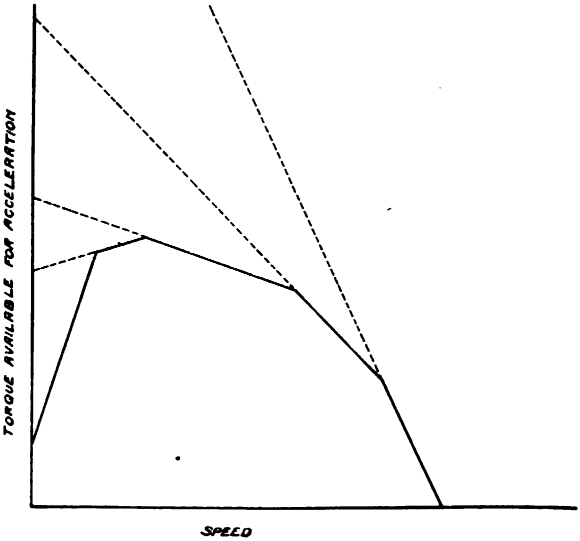

FIG. 2

By combining equations 1, 2, and 3, we obtain the following differential equation,

$$d v = \left(T_1 + \frac{T_2 - T_1}{v_2} v \right) \frac{g}{w}\, d t$$

From this we obtain by integration,

$$t = \frac{w v_2}{g (T_2 - T_1)}\, l n \left[\frac{T_1 + \frac{T_2 - T_1}{v_2} v}{T_1 + \frac{T_2 - T_1}{v_2} v_1} \right]$$

For cases where the torque decreases the following form of the formula is more convenient,

$$t = \frac{w\,v_2}{g\,(T_1 - T_2)}\;ln\left[\frac{T_1 - \dfrac{T_1 - T_2}{v_2}\,v_1}{T_1 - \dfrac{T_1 - T_2}{v_2}\,v}\right]$$

For constant torque, we obtain of course,

$$t = \frac{(v - v_1)\,w}{T\,g}$$

The speed-time curves can be directly calculated from these formulas.

From the motor characteristics it is possible to plot a curve showing the relation between losses and speed. From such a curve, and the speed-time curve, a curve giving the losses at any time during the starting period may be plotted. When starting is not frequent, it is sufficient to figure the heating of the various parts for one start from the heat capacity of the parts under the assumption that no cooling takes place during the starting period. This assumption will of course give somewhat too high values, so the figures will be on the safe side. When the starting is frequent, the time-loss curves of the starting period may be used in combination with the curves for the running periods for figuring the continuous average losses. Figuring this way, it will be found in many cases that the heating is not at all serious. By properly designing the motors for the purpose, it has been possible to use squirrel-cage motors for

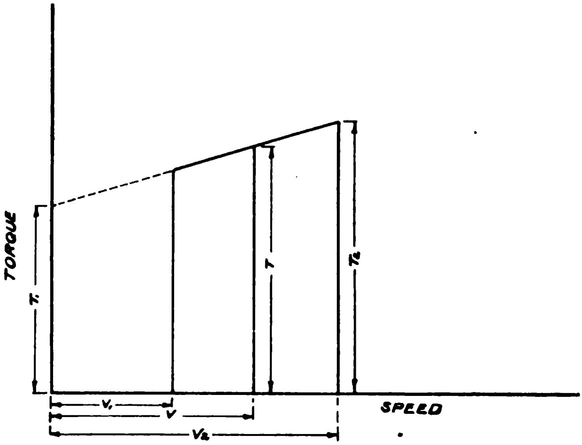

FIG. 3

three reversals per minute, continuously decelerating and accelerating with a comparative large mass. This, of course, was in cases where the large current drawn from the line was of no importance.

If a motor stand for some time, combustible dust accumulates on the resistance rings. When the motor is started the rings get hotter and the dust goes up in smoke, giving the impression that the motor insulation is smoking, while in fact the latter is not affected at all.

Mr. Gray says that the temperature-rise of the primary copper is virtually independent of the iron losses. This has been my experience. I use a very simple method of estimating the temperature-rise of an induction motor without knowing the dimensions of the winding.

The temperature-rise of the primary copper can be found by the equation

$$T_1 = T_0 + \frac{F_1}{F_{vent} \times \left(1 + \frac{v}{1970}\right)} \, . \, A\,S_1 \times S_1$$

T_0 = Temperature rise at primary copper losses = 0.
F_1 = A constant largely depending upon the type and secondary losses; further upon length of iron, ventilating ducts, and pitch.
vent = A constant depending upon the velocity and volume
F of the cooling air.
v = Speed of rotor in feet per minute.
$A\,S_1$ = Ampere bars per inch of circumference.
s_1 = Copper density in amperes per square inch.

This formula will be a great assistance in beginning a design, as it compares the different types and ventilating devices.

If the temperature rise of the primary and secondary copper is plotted in the ratio of the primary and secondary losses, the points will lie on practically straight lines and cut the ordinate at watts = 0 at a certain temperature-rise (0.3 degrees cent. see Fig. 8 of Mr. Gray's paper).

For the calculation of the secondary copper temperature rise a similar method can be used. In most cases the temperature-rise of the iron may be said to be equal to that of the primary copper. The application of blowers allows an increase of from 2 to 3.5 times in the primary and secondary losses. For the machine given in Mr. Gray's paper, Fig. 20, the temperature-rise may be figured as follows:

Assume for 1 kw. primary losses $A\,S_1 = 500$ $s_1 = 1800$ amperes per square inch.

Fvent = 1 without blowers.

$$25 \text{ cycles } T_1 = 10 + \frac{81.10^{-6}}{1\,(1 + 1.64)} \; 0.500 \quad 0.1800 = 37.6° \text{ cent.}$$

40 cycles $T_1 = 10 + \frac{81.10^{-6}}{1\,(1+2.71)}\ 0.500 \quad 0.1800 = 29.7°$ cent.

60 cycles $T_1 = 10 + \frac{81.10^{-6}}{1\,(1+4.06)}\ 0.500 \quad 0.1800 = 24.4°$ cent.

with fans

25 cycles $T_1 = 10 + \frac{81.10^{-6}}{2.1\,(1+1.64)}\ 0.500 \quad 0.1800 = 23°$ cent.

It was tested 37.5° – 28.5 – 25° cent.

Fvent has been increased 100 per cent.

For high-voltage machines with heavy insulation, special attention should be paid to the highest temperature-rise of the copper. The proposed temperature-rise of 85 per cent, if measured on the coil-ends, seems to be far too high for cotton insulation.

A paper to be presented at the 239th meeting of the American Institute of Electrical Engineers, New York, October 8, 1909.

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(*Subject to final revision for the Transactions.*)

TELEGRAPH AND TELEPHONE SYSTEMS AS AFFECTED BY ALTERNATING-CURRENT LINES

BY J. B. TAYLOR

General. In the early days of the electrical industry the telegraph practically had the field to itself. The telephone and electric light were introduced at about the same time, and later on the alternating-current systems gradually came into general use for lighting, general power, and railway purposes. At the outset, the telegraph systems made use of earth return and continue to do so at the present day. The telephone systems started out using an earth return, but soon found that satisfactory service, except in isolated cases, could be obtained only with metallic circuits. The power systems (this term includes alternating-current systems whether used for lighting, for power or for railway purposes) have until recently almost invariably used metallic circuits, which, when properly installed and under normal conditions, cause little interference to telegraph and telephone lines. Abnormal conditions, however, such as grounds, open circuits, and the like, upset the normal balance, giving strong external fields, both electrostatic and electromagnetic, which are likely to make trouble for sensitive systems in the immediate neighborhood. Recently the single-phase railway system has come into prominence. With this system the conditions are continuously very similar to those conditions which exist occasionally but of short duration on the power systems.

The great increase in the transmission industry means that power circuits are continually becoming longer, voltages higher, and the amount of energy transmitted greater, with more or less corresponding increase in disturbance to the weaker brothers. Steam railroads have in many cases presented the most natural and logical right of way for pole lines, with the result that power wires and signaling lines are likely to be in proximity.

The telegraph, telephone, and power systems, while rendering different classes of service, are all essential to present methods of living and carrying on business. The purpose of this paper is to give a general statement of power transmission and telegraph and telephone conditions as they exist, with special reference to combinations which may make trouble if simultaneous operation is attempted in too close proximity.

It should be borne in mind that induction between circuits is a mutual affair, the principle distinction being that a high-voltage transmission line conveying perhaps 1000 to 5000 kw. is not disturbed by, nor even able to detect, a few extra volts derived by induction from a telegraph line on the other side of the highway. The converse of this proposition is by no means true, and this points to the desirability of power transmission systems doing everything possible to keep the stresses and strains in the ether within the boundaries of their own right-of-way, and the equal importance of telegraph and telephone apparatus and lines being so constructed and maintained that they will be as far as possible independent of stresses and strains which may be unavoidably introduced into the portion of the ether which they occupy. An adequate consideration and solution of the problem necessarily involves an intimate study of the characteristics and sensibilities of telephone and telegraph instruments as well as a calculation of disturbing electromotive forces and currents induced in their circuits with values depending upon all the various features of construction and operation of the power lines.

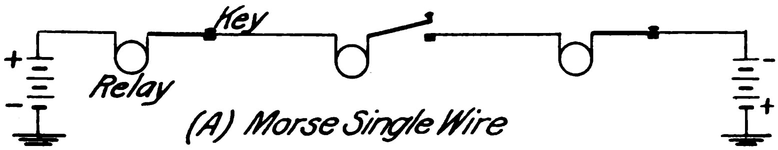
Telegraph systems. The telegraph circuit, with few exceptions, is made up of a single wire and earth return. The typical Morse system is represented in Fig. 1, Diagram A, showing relays, keys, and a battery at each end of the line. Relays are usually of 150 ohms resistance and the normal working current is in the neighborhood of 40 milliamperes, although many circuits having a large number of intermediate stations make use of 37.5 or 35-ohm relays and on these circuits the current will probably average nearer to 0.050 than to 0.040 milliamperes.

Diagram B shows a typical arrangement of duplex circuit, in which case relays are polarized with differential windings. This arrangement does not permit the insertion of intermediate stations.

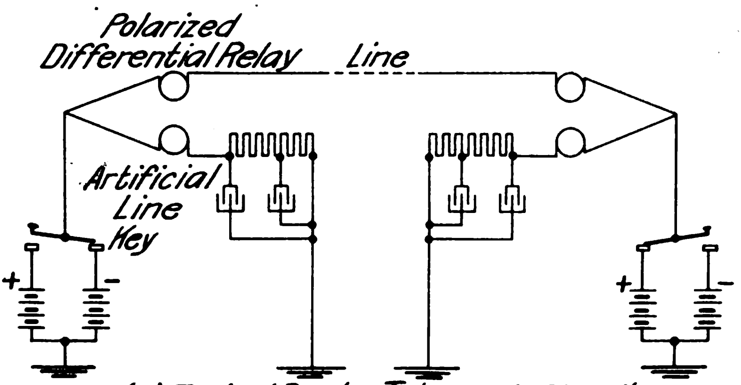
A quadruplex system is an extension of the duplex, by placing in circuit a second differential relay so adjusted as to respond only to currents greater than those required for operating the polar relay, and means for changing the strength of current.

The duplex system ordinarily uses current of 12 to 15 milliamperes and the quadruplex uses three to four times this current, say 35 to 50 milliamperes, for actuating the neutral relay.

As far as the main line circuit is concerned, these two systems include nearly all of the various types of high-speed, automatic printing telegraphs, etc., the main difference being in the types of relays and local apparatus controlled by them, as well as the duration and polarity of signals and the code used. For example, the Rowland system recently described in an Institute paper,* is essentially a duplex system, the octoplex capacity being obtained by assigning the line for short intervals of time to one of the four operators at each end in succession.



(A) Morse Single Wire



(B) Typical Duplex Telegraph Circuit

FIG. 1

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* The Rowland Telegraphic System, by Louis M. Potts, PROCEEDINGS, A. I. E. E., April 1907, p. 409.

The frequency of the currents for hand transmission probably averages in the neighborhood of 8 to 10 cycles, although this is a crude way of putting the matter, as signals are short and long, interspersed with spaces. The Wheatstone automatic system, when working up to an extreme speed of 600 words per minute, gives alternate pulses in the line corresponding roughly to 240 cycles per second. The Rowland system as described uses approximately 100 cycles for octoplex working and 50 cycles for quadruplex working. The inertia of the armature of the standard 150-ohm relay, and other features of its magnetic design, will not permit this relay to follow very rapid alternations so that on the high-speed, automatic-working, special constructions of the Siemens or Wheatstone type are used.

All relays are provided with ready means for adjusting the air-gap, length of stroke, and tension of retractile spring, where such is used. Any data on the sensibility of relays are therefore greatly dependent on these various adjustments. Furthermore, adjustments are continually being made by the operators to compensate for variable leakage of the line, due to weather conditions, and also to compensate for variable current and lag, depending on relative positions on the line of sending and receiving operators. It is therefore impossible to make a general statement that a certain number of milliamperes added to or subtracted from the normal direct current, due to inductive influence, will disturb or completely upset the working, and that a lesser superimposed current will not be felt.

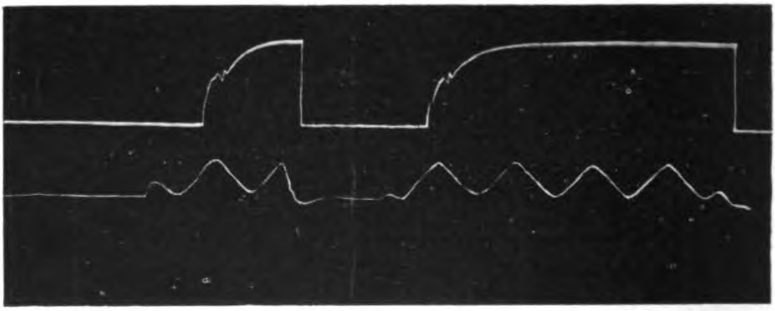


FIG. 2

Experienced operators recognize their friends by the way the instrument "talks," quite as distinctly as those who are not operators recognize handwriting or the sound of the voice. This is stated to bring out the point that disturbances on the line which do not actually upset the working may make considerable difference in the comfort or state of mind in which the operator does his work.

In order to give some idea of the characteristics of the standard 150-ohm relay, tests have been made under the following adjustments:

Magnetic air-gap 0.07 in.

Length of stroke at contacts 0.015 in.

Spring tension so that relay would pick up at 40 milliamperes direct current, and let go at 30 milliamperes.

Under the above conditions, 25 cycles alternating-current current to cause relay to chatter on the back stop, 31 milliamperes.

Current to cause relay to pull up to front stop sufficient to start chattering in local sounder, 62 milliamperes.

With 40 milliamperes direct current in relay — superimposed 25 cycle current to cause relay to break contact on the front stop, 20 milliamperes.

As stated above, different adjustment of gap, length of stroke, and spring tension would give quite a different set of current values. Oscillograms, Fig. 2 shows the current in main line relay and in local sounder with 25-cycle alternating current superimposed on line.

The impedance of a standard 150-ohm relay at 25 cycles is given below at different air-gaps.

Air Gap	Impedance	25-cycle current when measuring impedance
0.12 in	465 ohms	89 milliamperes
0.11 "	474 "	88 "
0.10 "	488 "	86 "
0.08 "	515 "	82 "
0.06 "	555 "	77 "
0.05 "	580 "	74 "
0.04 "	650 "	67 "
0.03 "	725 "	61 "

Special apparatus on telegraph lines. Where a telegraph disturbance is slight, improvement may be effected by one or more of the following devices:

Increasing impedance of line.

Increasing working current.

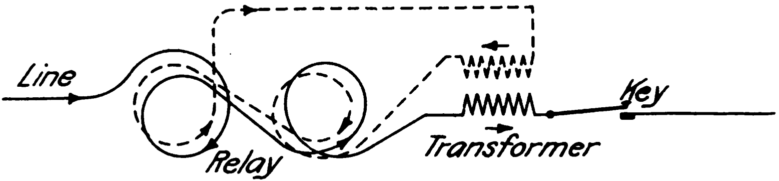
Shunting apparatus with condensers or non-inductive resistance.

Placing short-circuited secondary winding on relay.

Placing neutralizing winding on relay.

Using back contact of relay with reversing sounder.

By placing additional resistance and reactance in the telegraph circuit, the superimposed alternating currents will be reduced in proportion to the increase of impedance. At the same time the battery should be increased to maintain the normal direct current, at its usual value. By working the line at a higher value of direct current, the percentage increase and decrease due to induced alternating currents will be less, with consequent reduction in the disturbance of the relay. Shunting the relay with a condenser or a non-inductive resistance diverts a portion of the alternating current from the inductive winding of the relay. While a condenser bridging a single relay will help this particular instrument, it will not help the line as a whole. By placing the relay winding over a thick copper tube or on a copper spool, alternating currents will be induced in the copper tube which will tend to oppose the effect of the alternating current in the winding.



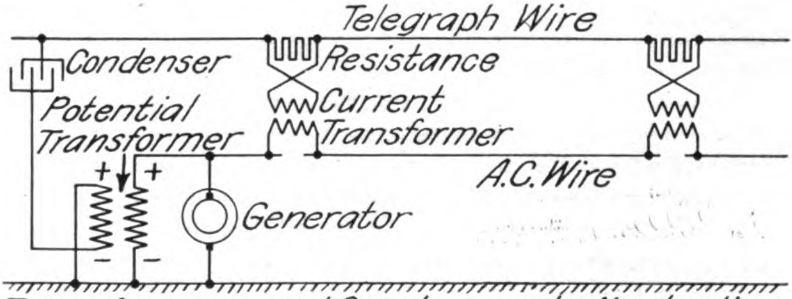
Differentially Wound Relay with Neutralizing Transformer

Fig. 3

In the second winding of a differential relay, currents in opposite direction to the alternating currents in the main winding may be introduced by means of a small transformer connected as shown in Fig. 3.

Since the signaling currents in a telegraph line are of the nature of alternating currents, it can be seen that any of the above choking, shunting, absorbing, or neutralizing devices will tend to make the action of the relays sluggish; and as soon as the frequency of the signaling currents equals or exceeds that of the induced currents, these devices will become a hindrance rather than a help.

When the telegraph line is open, the relays are against their back stops; and with the line open, there would be no current, either direct or alternating, except for leakage and capacity effects. The air-gap is also at its greatest, so that the relay is less likely to be disturbed while on the back contact than when on the forward contact. By taking the local circuit from a back contact on the relay, and adding a reversing sounder the inductive disturbance may be less noticeable. This is a combination known as a "bug-trap," having been devised by Mr. Edison in the early days of the quadruplex. It is also possible to accomplish a similar result by using a flexible or spring contact on the relay. Such a contact allows a slight vibration of the armature without causing the local circuit to open.



Transformers and Condensers to Neutralize Electro-magnetic and Electro-static Induction

FIG. 4

The devices considered just above are only palliative remedies. When the amount of power transmitted, length of line, or small separation of the two circuits is such as to make the disturbance severe, definite neutralizing conditions must be introduced.

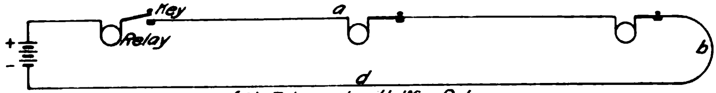
If we can introduce into a telegraph circuit voltages equal and opposite to those derived by electromagnetic induction, and at the same time supply to the line the charge demanded by electrostatic induction, we shall succeed in neutralizing the inductive effects. Fig. 4 shows one way in which this idea may be worked out. Current transformers connected in a disturbing wire introduce into the telegraph line a voltage proportional to the current in the transformer. Since on a railway the position of the load is shifting, it would be necessary to divide the line into sections, with a transformer for each. The shorter the sections, the more exact the neutralization. Electrostatic induction is neutralized by using condensers in connection with potential transformers as indicated. The proper charge can be obtained by varying the capacity of the condensers or the voltage applied to them.

Instead of using current derived directly from the disturbing wire for the purpose of neutralizing, this neutralizing current may be derived from a special neutralizing wire placed close to the disturbed telegraph wires. Since the neutralizing wire has practically the same exposure as the telegraph wire, the same voltage will be induced in each, and a suitable 1:1 transformer makes proper change of polarity so that voltage induced directly in the telegraph wire is annuled by that induced in the neutralizing wire. This arrangement while effective is not exact, on account of magnetizing currents, earth currents, phase distortion, and the like.

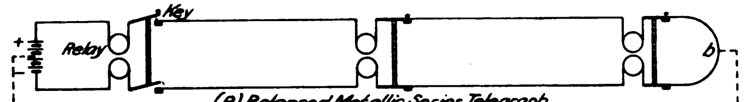
Metallic circuit telegraph systems. In spite of all of the arrangements of alternating-current circuits which may be employed to eliminate or reduce disturbing inductive effects, in some situations it may be cheaper or more desirable to make use of a metallic circuit for the telegraph. Any form of metallic circuit telegraph will be less sensitive than a circuit with earth return, but the full benefit of the metallic circuit is to be derived only when following the "balancing" principles to be stated more in detail when discussing the telephone.

The metallic telegraph may be operated on either the series or multiple connection, and either of these connections properly installed will be perfectly balanced. The same might be said of the telephone system, although as far as the writer is aware a balanced metallic series telephone system has never been used.

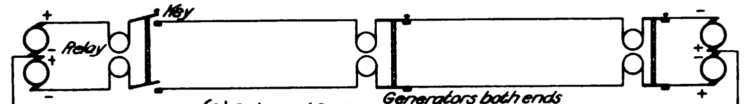
Inductively considered, corresponding points on the two wires of a telephone or metallic circuit telegraph system are at the same potential. Slight differences in potential due to the difference of field strength in the 10 or 12 in. separating two wires in practice is made insignificant by frequent transpositions, and small charging currents must flow back and forth from one section to another, due to the slight difference of potential between the two wires. Pieces of apparatus such as telephone receivers, bells, or telegraph relays, "bridged" between the two wires are, therefore, free from inductive currents. If the apparatus be connected in series, in order to preserve the balance it must be differentially wound, an equal winding being cut into each side of the line. With such an arrangement, on account of the differential action of the two windings, induced currents or electro-



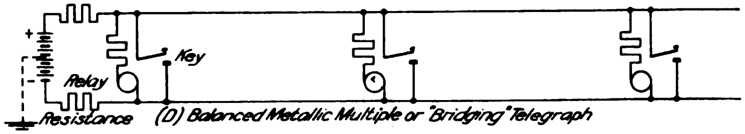
(A) Telegraph with Wire Return



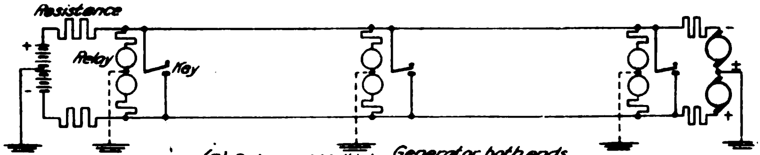
(B) Balanced Metallic Series Telegraph



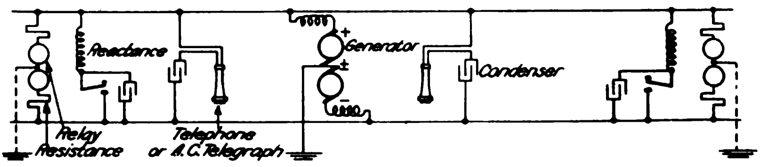
(C) Balanced Series Generators both ends Neutral grounded



(D) Balanced Metallic Multiple or "Bridging" Telegraph



(E) Balanced Multiple Generator both ends Neutral grounded at several points



(F) Bridging Connections for Simultaneous Telegraph and Telephone or Duplex Telegraph D.C. and A.C. with Intermediate Stations.

FIG. 5

static charges flowing from one section of the line to another section will not affect the instrument.

Fig. 5 shows several connections which may be used for the metallic circuit telegraph. Diagram A shows an ordinary series telegraph system with wire return in place of earth return. If the conditions are such that electrostatic effects can be neglected, this arrangement, though not balanced, will be satisfactory.

Diagrams B and C show a balanced metallic series telegraph. In this case the relay must have double windings differentially connected. Double-pole keys are also essential. Diagram B shows a battery, which may be grounded at the neutral point or may be ungrounded; and similarly the ground at the end of the line, *b*, may or may not be employed. The purpose of the neutral ground in all of these cases is to keep the system as a whole at approximately earth potential. In Diagram C, generators are shown at each end of the line, the neutral connection being grounded. With this arrangement, balanced metallic circuit lines may be connected to the usual office generating equipment, as this equipment consists of positive and negative machines at approximately the same voltage, with one terminal grounded.

Diagrams D and E show a metallic circuit telegraph system with relays connected in multiple, or bridged between two sides of the line. With this arrangement it is essential to have the relay wound to as high resistance as practicable, and it may also be advisable to place additional resistance in series with each relay. Resistances are inserted between the battery, or the generator, and the line of sufficient value so that closing any one of the keys will cause the potential at all the relay terminals to fall sufficiently to cause the relays to operate. Diagram D shows a battery at one end of the line only, while diagram E shows an energy supply from both ends. This latter diagram shows the neutral points of the battery and generators grounded, and the possibility of grounding the neutral points of relays is also indicated.

Diagram F shows a combination of the metallic-circuit bridging telegraph with the metallic-circuit bridging telephone. In place of the telephone there might be substituted one of the various forms of alternating-current telegraph. This arrangement, being balanced for both the alternating-current telegraph instruments, as well as for the direct-current instruments, would be free from inductive disturbances, and similarly would not cause disturbance in neighboring circuits, a trouble frequently experienced with alternating-current telegraph systems. In other words, the two wires so connected result in two independent circuits (with intermediate stations if desired) thus providing the service facilities that the same two wires do when connected as simple grounded lines.

An incidental advantage of the bridging connection of telegraph lines is the ability to establish an emergency or temporary station at any point by merely attaching suitable apparatus to the two wires.

Telephone systems. As stated previously, the early telephone systems copied telegraph practice in making use of a single conductor with earth return, but since it is only in isolated cases that a grounded telephone is at all satisfactory, and since when in the vicinity of other wires it is almost invariably quite unsatisfactory, we shall, for the purpose of this discussion assume throughout that the telephone is operated on a two-wire metallic circuit.

The whole science of having a perfectly quiet telephone line is dependent on the Wheatstone bridge principle, that no current will flow in the wire or instrument connecting two points at the same potential, even though these two points are on conductors carrying currents of considerable magnitude. The practical application of this principle requires that each wire of a telephone circuit shall have the same resistance, the same inductance, the same capacity, and the same insulation resistance; and more exactly, that these conditions of equality shall hold, not only for the circuit as a whole, but for each and every short section of the circuit. Still more exactly these conditions of equality must hold for the entire range of frequency to which the apparatus is sensitive and for currents of any magnitude that are likely to be introduced into the circuit.

In practice these ideal conditions can be attained only approximately, even after making numerous transpositions of the two conductors. An Institute paper by Mr. F. F. Fowle,* dealing with the question of transpositions, and the practice of making these transpositions sections 0.5 mile long in order to reduce to a negligible amount the cross-talk from neighboring telephone circuits, shows the extreme sensibility of the telephone receiver.

The varieties of telephone apparatus, both signaling and talking, and the methods of connecting to meet various requirements, are innumerable. The two general types of magneto and common-battery systems are shown diagrammatically in Fig. 6.

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* "The Transposition of Electrical Conductors," Trans. A. I. E. E., Vol. XXII., p. 659.

Where the telephone circuit serves also for a telegraph line, the fact that the telephone is on a metallic circuit does not make the telegraph circuit metallic. For this reason, the same general considerations that apply to any telegraph line will apply to telegraph service obtained from telephone wires in the usual way.

Ringing, or calling currents, on telephone lines are commonly alternating at the rate of 16⅔ cycles per second, although lately the increased use of harmonic ringers calls for frequencies as high as 66. Hand generators are commonly wound to give between 50 and 100 volts on open circuit; this may be reduced to 10 volts or less at the end of a long line with many stations, and still be expected to ring the bell. Bells are commonly wound to 1000 ohms resistance, although many of the longer lines, with many stations use bells wound to as high as 2500 ohms resistance. The current taken by a standard 1000-ohm bell at 16⅔ cycles, 75 volts, is approximately 25 milliamperes. Fig. 7 shows the regulation of a five-bar hand magneto of standard type when connected with a load of 1000-ohm bells.

Numerous forms of protective devices are employed on telephone lines but nearly all consist of fuses and discharge gaps to ground, made up of small pieces of carbon separated by perforated mica, only a few mils in thickness. 300 to 400 volts is probably a fair figure for the breakdown point of these carbons when separated by 5-mil mica.

The actual magnitude of currents in telephone lines, resulting from speech sent into the transmitter, cannot be given with any accuracy. The strength of the battery, the special characteristics of the transmitter, the ratio of transformation in the induction coils, the constants of the line, not to mention the intensity of the voice, and the manner in which it is directed into the transmitter—all these are factors affecting the value of this current. For the purposes of this discussion, however, we may assume that on short lines the current may be as high as two or three milliamperes, while at the receiving end of long lines the current may be less than the one hundredth part of this and still be sufficient for the proper understanding of conversation.

The frequency of speech currents (for commercial telephone quality) is probably included between 200 and 2000 cycles.

Probably the most important of these currents lie between 700 and 900 cycles. The writer believes it has been for some years the practice of the telephone companies to consider 800 cycles as the one frequency best representing the general range, and to make use of this frequency from small alternating-current generators when making quantitative measurements on different pieces of apparatus. How this figure was originally arrived at, the writer has not been informed, but observations of telephone speech currents, which he has carried on by the aid of the oscillograph, tend to show that, roughly, 700 cycles is the prominent frequency in a man's voice. It is somewhat higher, say 900 cycles in a woman's voice.

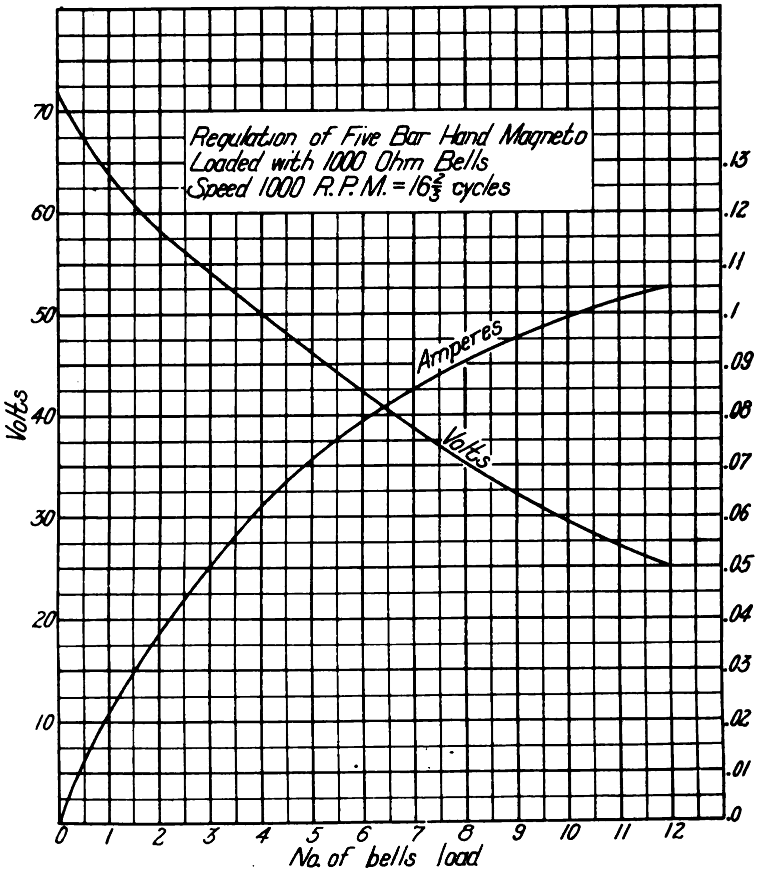

FIG. 7

Fig. 8, shows a musical scale on which are noted the various frequencies referred to in this dissertation, and other frequencies that may serve to give a clearer idea of the various tones referred to.

The difficulty of naming a value of current sufficient to cause interruption or disturbance, mentioned while discussing the telegraph system, is even greater when considering the telephone system. To state the number of years of continuous sound that could be produced by one kilowatt-hour will serve no useful purpose in this paper; but of more practical interest are the curves of sensibility to different frequencies as given by Lord Rayleigh* and by Mr. Fowle† in the paper previously referred to, and by the writer's recent experiments. These curves, Fig. 9, were all made on a different basis of comparison, which accounts for the large differences in actual magnitudes of current; but attention is particularly called to the fact that, comparatively speaking, the sensibility, at say, 25 cycles, as shown by all of these curves, is not even of the same order of magnitude as the sensibility at, say, 600 cycles.

These curves are combined physical and physiological effects, as no attempt has been made to separate the influence of natural period of the telephone diaphragm. The size and weight of diaphragms in use seem to have been derived empirically and the small difference among so many makes it worthy of note.

Fig. 10 shows oscillograph records of the vowel sound "I" (as in mach*i*ne) taken from two different makes of transmitter. Curves *A* and *B* were made with the same arrangement of induction coil and transformers between the transmitters and the oscillograph vibrator, while Curve *C* was made with the same transmitter as Curve *B*, except that a single induction coil or transformer was in the circuit. The close similarity between Curves *B* and *C* show that the distorting effects of a transformation must be very small. The great differences, therefore, between Curve *A* and the others must be due to the difference in natural period, and amount of damping, of the two makes of transmitter.

Physiological phenomena having more or less bearing on this question of telephone sensibility are briefly stated below.

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* "Theory of Sound," Vol. I, p. 473.

† "The Transposition of Electrical Conductors," Trans. A. I. E. E, Vol. XXII, p. 659.

A. The lower limit of audibility is given by Helmholtz* as 25 to 30 cycles. Later investigation by Messrs Preyer and Ellis† place 15 cycles as the extreme low limit. Tests of this sort depend almost entirely on the intensity of the sound, and there is great danger in confusing some of the harmonics with the

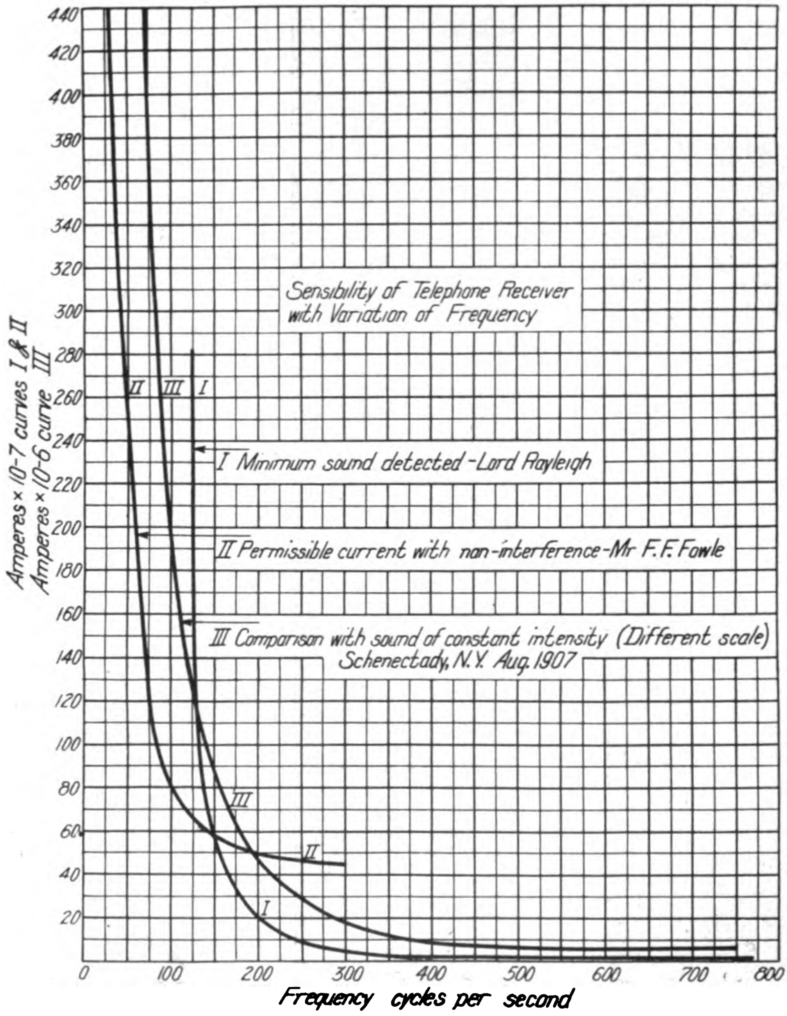

FIG. 9

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* "Sensations of Tone," Helmholtz, p. 116.

† "Sensations of Tone," Translator note, p. 116.

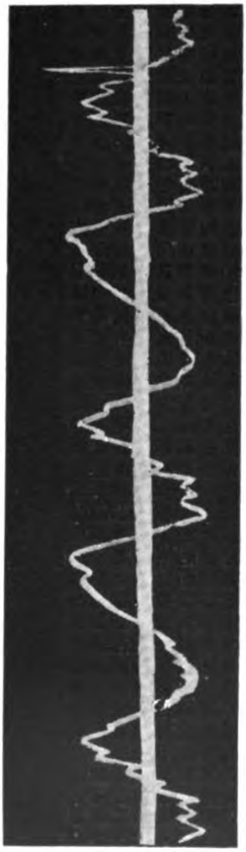

Fig. 10A

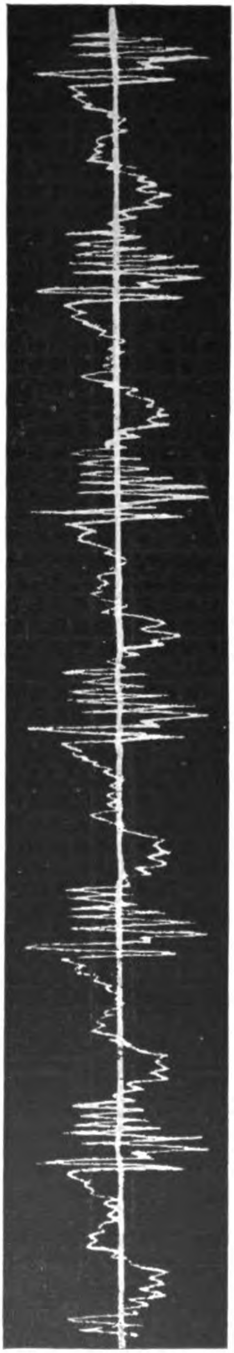

Fig. 10B

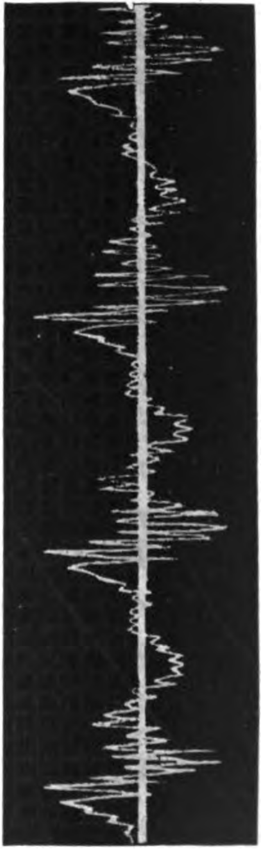

Fig 10C

fundamental. The writer believes that he has actually heard a 25-cycle tone from a telephone receiver, but this could be heard only after taking precautions to obtain a smooth wave shape, by passing a comparatively large current through the receiver, and by holding the receiver very tightly against the ear, in a sound-proof booth. The vibration of the diaphragm at 25 cycles could be plainly felt by touching with the finger at a current value much below that required for an audible sound.

B. The upper limit of audibility, while apparently more definite, varies with different observers, 30,000 cycles being the figure ordinarily assigned for the upper limit, although some persons may hear sounds as acute as those corresponding to 40,000 cycles. The telephone receiver is not well adapted to respond to these very high frequencies, and a rough test made by the writer indicated that the sound was practically lost at 12,000 cycles, even though there was a pressure of 30 to 40 volts directly on the receiver terminals. When making this experiment it was noticed that as the high-frequency generator accelerated or came to rest there were certain frequencies which gave marked increase in sound. While investigation of this point has been by no means complete, the accompanying rough curve, Fig. 11 is given as a matter of interest. While on this matter, it should be noted that for musical purposes sounds higher than 4000 cycles are considered of little or no value.

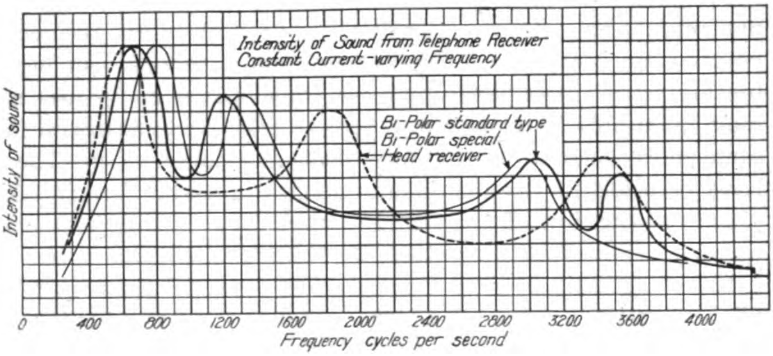

FIG. 11

C. Low tones tend to drown out or diminish the apparent intensity of higher tones.* The ear apparently fixes its attention on the lower tone. This point is well recognized by musicians who rate a complex tone according to its lowest partial, even though the magnitude of this partial is small compared to that of some of the higher harmonics.

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* "Theory of Sound," Lord Rayleigh, Vol. II, p. 444.

D. The ear itself, containing a column of air, should have its own natural period; this period Helmholtz places† in the neighborhood of e'''' to g'''', roughly, 2600 to 3200 cycles. Consequently the ear is especially sensitive to sounds corresponding to its own period.

E. Continuous sounding of a tone tends to deaden the ear to appreciate this particular tone.‡ Consequently, there is less difficulty in talking over a noisy telephone line where the noise is of constant pitch and intensity, as compared with the difficulty of talking over a line where the noise is continually varying in pitch, intensity and quality.

Telephones for high-tension transmission line service. Quick and reliable telephone service between generating and receiving points is an important factor in maintaining service over high-tension transmission lines. Power transmission companies almost invariably have their own private lines, and usually on the same poles or structures that carry the transmission wires. There have occasionally been serious accidents to users of such telephones at the time of accidental contact between telephone and power wires; and at other times the inductive effects due to unbalanced conditions cause differences of potential between telephone system and ground, which can by no means be neglected. The telephone is, therefore, very likely to be out of commission just at the time when tangles on the power system make communication necessary in order to resume service. Various points in connection with this phase of the transmission problem were well brought out in an Institute paper* and accompanying discussion several years ago.

In order to safeguard the users of telephones, the telephone insulating transformer shown in Fig. 12 has been developed. This transformer is given a high-potential test of 25,000 volts between windings which come to line and those connected to instrument. The combination disconnecting-switch, fuse, and lightning-arrester, shown in the same cut, has the ordinary

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† "Sensations of Tone," p. 116.

‡ "Theory of Sound," Lord Rayleigh, Vol. II, p. 446.

* "The Transposition and Relative Location of Power and Telephone Lines," P. M. Lincoln, Trans., A. I. E. E., Vol. XX., p. 245.

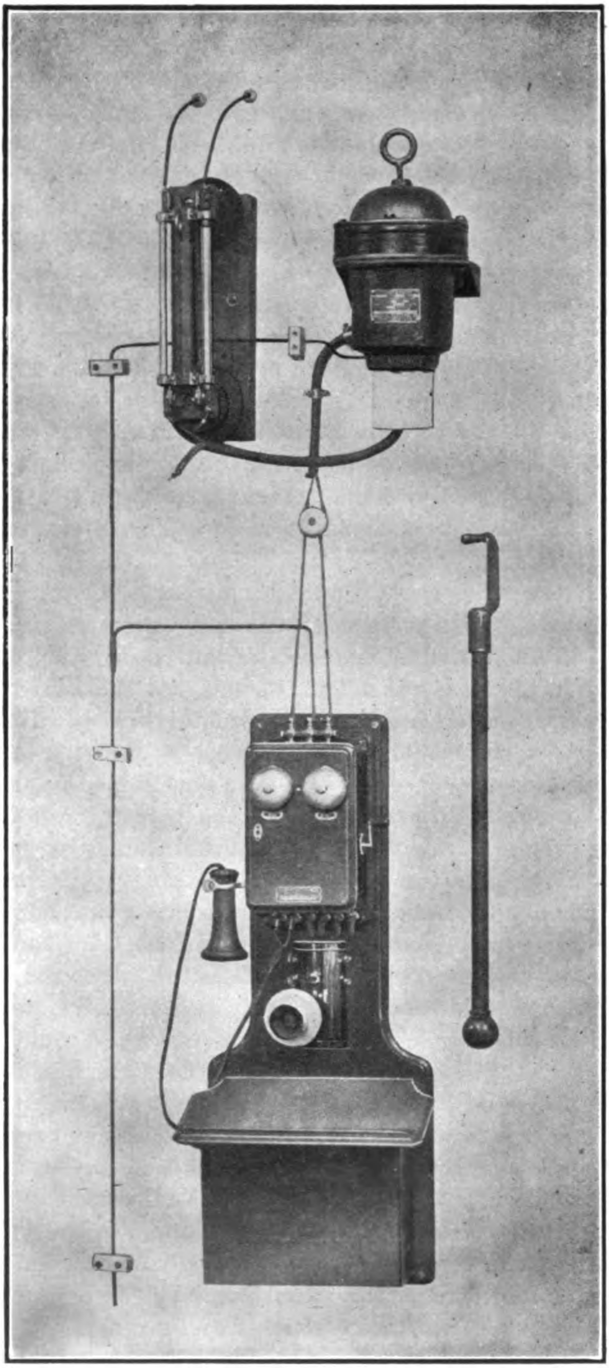


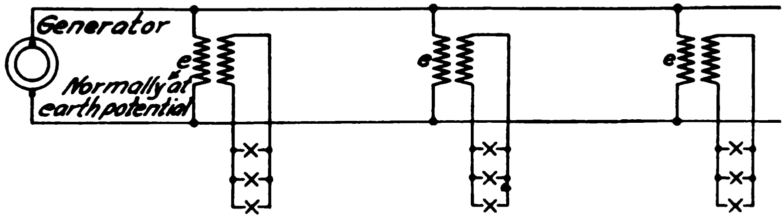
Fig. 12—Installation of telephone, with Y-109 insulating transformer and combination fuse lightning-arrester and disconnecting switch.

small-gap carbon plates across the terminals of the transformer, but such gaps are not used between line and ground. Discharge gaps to ground are made adjustable, the intention being to set these just beyond the point that the maximum induced potential, under abnormal conditions, will strike. As this potential is not likely to be much above 8000 or 10,000 volts, the 25,000-volt test insulation in the transformer is expected to protect the instrument even in the possible event of actual contact between telephone lines and wires of systems operating at 25,000 volts or higher. Both primary and secondary of this transformer may be double wound, permitting series or parallel connection, as may be best for various line conditions, and also making available a neutral point which may be grounded where such a ground is serviceable. The neutral point is of service in case it is desired to signal or telegraph over the telephone line.

On any telephone system eternal vigilance is the price of first-class service. The insulation always has a tendency to become worse, and change in resistance at connections will upset the balance. So long as the telephone line has the field to itself, the closest attention need not be paid to these points. However, when in the neighborhood of other conductors, departure from a theoretically perfect balance immediately begins to be felt, and much more attention must be paid to transpositions and insulation. While the writer states nothing new, he wishes here to emphasize the importance of bringing the insulation of the telephone system as a whole into first-class shape before wasting any time or money on transpositions. In many cases, on a telephone line becoming unsatisfactory, it is the practice to cut in more transpositions. If these have previously been located at every tenth pole, they may be doubled up, placing one at every fifth pole. Probably there are few telephone lines, on the same poles with power lines, where transpositions at every fifth pole are any more effective than at every tenth pole. While with some forms of transposition there is no objection to placing as many as the line will hold, those forms which involve cutting the wires and making splices are likely to have imperfect joints, with consequent loss of balance. In general, the more transpositions the more likelihood of high-resistance joints. We have also seen a fantastic arrangement of see-sawing the two conductors of the telephone line up and down from pole to pole in the vain hope that a noisy line would be quieted in this manner.

In a recent instance, additional transpositions were placed in a telephone line, and also in the power line, with small improvement in service. The trouble was eventually found in some transmitter dry batteries, which were located away from the instrument in a damp location. It is the habit of telephone manufacturers to make common connections between the primary and secondary circuits of their instruments in the endeavor to save, either a few inches of wire, or an extra contact at the hook switch. This means that unless attention is paid to every inch of the telephone system, it is poor economy to replace the cheap pony glass on the outside line by high-grade porcelain.

Alternating current systems.—The earliest alternating-current systems were operated single phase and used mainly for lighting purposes, from a large number of small transformers. This system is represented diagrammatically in Fig. 13. Being a metallic bridging system free from grounds, the fields which may cause disturbance to neighboring wires are comparatively weak. Since these lighting systems usually supply the same customers that are also supplied with telephone service, local telephone lines are especially likely to be in proximity to such circuits. The further objections of property owners to tree-trimming, and to duplicate pole lines in residence sections, usually result in occasional grounds on the lighting circuit, or the telephone circuit, or both, with attending noisy lines. Since the various feeders in the local distribution are connected in parallel to the same bus-bar, a ground on any one feeder upsets the electrostatic balance of all the others. It is also possible on such a system to have a ground simultaneously on both sides of the circuit, which may result in unbalanced currents and

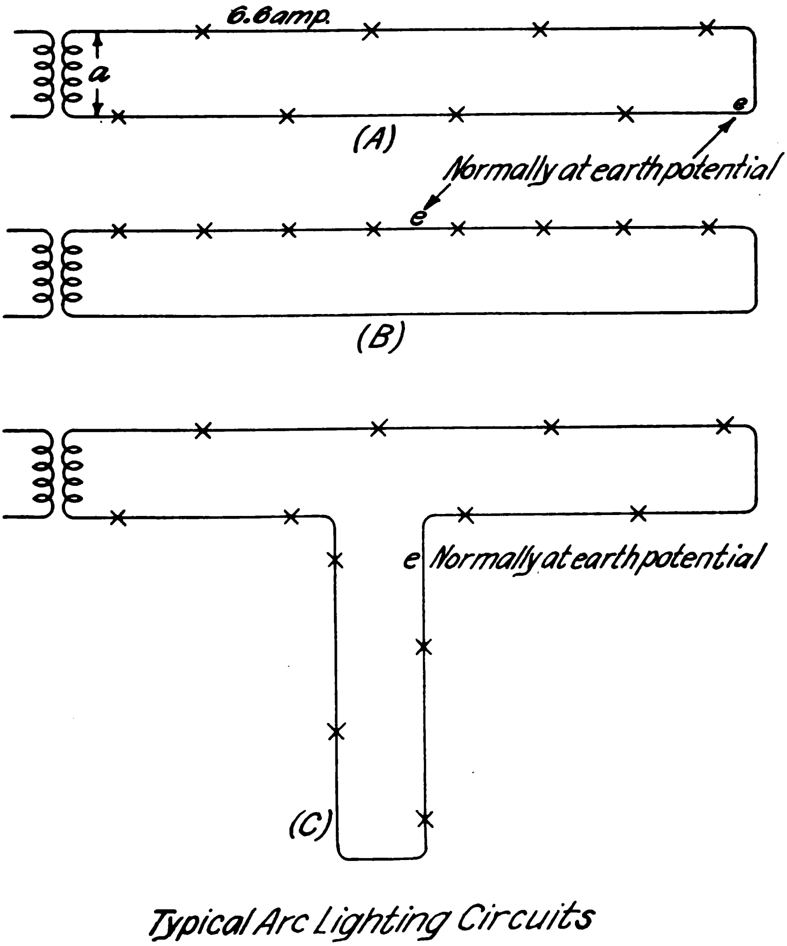


Representative Diagram for Single-phase Lighting System

FIG. 13

electromagnetic inductive effects; but on account of the usually high resistance of tree grounds, etc., such currents are likely to be small and of slight disturbance compared with the unbalanced electrostatic effect.

An ideal metallic circuit telephone system should not be affected by exposure to fields of any strength, but the great differences between ideal and practical construction are such that not infrequently a heavy ground on a 2300-volt local lighting system will be felt on all of the telephone lines in the exchange.



Typical Arc Lighting Circuits

FIG. 14

Another local alternating-current system is that used for series arc lighting, represented diagrammatically in Fig. 14. These circuits usually carry 6.6 amperes, and with 50 lamps in the circuit the potential between wires at the point *a* is approximately 4000 volts. This potential is reduced by 80 volts as each lamp is passed in succession. More inductive disturbances have been felt from circuits of this character than from the typical lighting circuits discussed above, mainly in instances where the lamps have been connected to the wires with little regard to preserving the balance. For example, diagram B shows all the lamps connected in one side of the circuit, the other side serving merely as a return. In such a case that point of the system at earth potential would be somewhere near the point indicated, instead of at the end of the line. In other cases the two sides of the circuit are not kept together, in the attempt to save wire by looping down one street and up another as shown in diagram C. A side-branch cut in as shown in diagram D tends to give a similar unbalanced electrostatic potential as the arrangement B, although this arrangement is in general not so bad as where all the lamps are cut into the same side of the circuit. In addition to the greater inductive disturbances from unsymmetrical placing of lamps and looping of circuits, these arc circuits are more likely to be grounded than the multiple lighting circuit, partly on account of the higher voltage.

The next system to be considered is the three-phase system represented in typical diagrams of Fig. 15. *A* represents the simple three-phase system supplying three-phase load, either through banks of transformers or directly. With this system the very nearly equal capacity between each of the wires and ground tends to maintain the neutral point of the system at earth potential as indicated by *e*. At any given instant the algebraic sum of the potentials of the three wires (measured to earth) is equal to zero, and the algebraic sum of the currents in the three-wires at any location on the system, is also equal to zero. Consequently, unless the three-wires are widely separated, the external fields, both electrostatic and electromagnetic, are weak. An accidental ground on any one of the three conductors disturbs the electrostatic balance, with results similar to a ground in the single-phase system previously considered.

B shows a three-phase system used for both power and lighting. As indicated in this diagram, it is not unusual to extend any

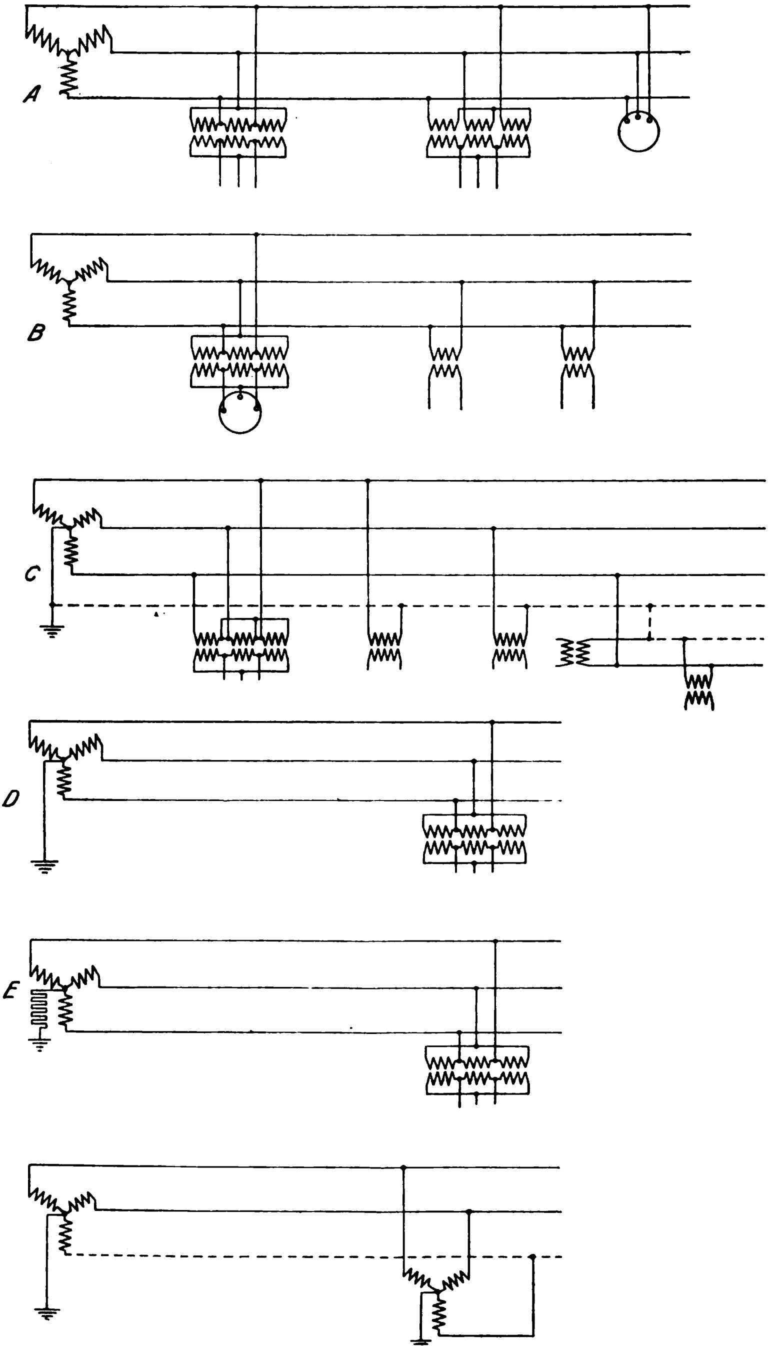


FIG. 15—Typical three-phase distributing systems.

two of the conductors to make a single-phase distributing line. This arrangement, even with perfect insulation of the system, displaces the neutral point from earth potential, as indicated by *e*, a greater or less amount depending on the relative capacities of the three-phase branches and single-phase branches. From such a mixed system we might, therefore, expect electrostatic induction. Electromagnetically, however, this system is as well balanced as the preceding. A similar condition may arise on a balanced system of distribution through the blowing of a fuse.

C shows a four-wire, three-phase system as occasionally used for combined lighting and power distribution. In this case a fourth conductor is connected to the neutral, which may or may not be grounded. Motors and three-phase transformer banks may be connected as in the simple three-phase system while lighting transformers are connected between any one of three conductors and neutral conductor. This system is on a par with *B*, when the neutral point is not grounded. When the neutral point is grounded, a single-phase branch as indicated between *d* and *e*, will obviously have the same effect as a single-phase line with one conductor grounded.

D shows a three-phase system with the neutral point definitely maintained at earth potential. Neglecting line drop and regulation of the system, a ground on any one conductor does not disturb the electrostatic balance but does upset the electromagnetic balance, as in this case the current, determined by the resistance of the fault and the earth return, flows over one wire and returns to the neutral through the earth.

E shows the neutral point grounded through a resistance. With this arrangement, a ground on one conductor will usually disturb both the electrostatic and electromagnetic balance. The relative disturbance of each sort depends on the resistance of the fault and neutral resistance.

F shows a three-phase system on which the neutral point is grounded at both the generating and receiving ends of the line. From the standpoint of disturbance, this is very similar to D. From the operating standpoint, the grounded neutral at both ends permits continued operation in emergency with either one or two of the wires out of service. When running on two wires, the electrostatic disturbance will depend on whether the third wire is alive without carrying current, or whether it is dead through being disconnected at both ends. Any operating condition which causes currents to flow from one neutral to the other through the earth, will also unbalance the circuit to some extent. In all of this discussion it has been assumed that the electrostatic capacity to ground of the generator and transformer windings is small compared with the capacity of the distributing wires whether in underground cables or overhead lines.

The practice of transposing three-phase lines varies between no transpositions at all to transpositions every mile. For the average system, transpositions are of no value unless the telephone or telegraph wires are near enough to be affected. Too many transpositions, besides being of little service, tend to weaken the line and increase the difficulties in locating trouble.

Harmonics and irregularities. When the electromotive force wave of a generator, as measured between the neutral and one of the terminals, contains third harmonics, and other harmonics which are multiples of the third, these harmonics are in the same phase relation in the three windings. Grounding the neutral point brings the potential wave of these particular harmonics on all three of the line wires in the same phase relation. Electrostatically considered, therefore, with reference to the third harmonic the three wires may be regarded as a single wire whose potential to ground varies at triple, and multiples of the triple, frequency. The possible resulting disturbance will depend entirely on the magnitude of these harmonics. The writer knows of but one case where trouble was experienced with telephone lines as the result of grounding the neutral point of generators, and in this case there was nothing to show whether or not the telephone line was in fair condition for exposure to the high-tension transmission line. In several tests made it has been impossible to tell, from the telephone line, whether the neutral connection was grounded or not. In one instance an ordinary telephone receiver was connected between ground and the neutral of a 2000-kw. 13,200-volt generator, in service and feeding, through several thousand feet of cable and six or seven miles of transmission line, a 1500 kw. synchronous converter. The noise was no greater than is occasionally heard on a commercial telephone line in trouble. This somewhat dangerous experiment was performed only after finding that the triple-frequency charging current on this system was too small to be measured on commercial alternating-current instruments.

Variable permeability and the hysteresis and eddy-current losses in transformers result in a distorted wave of exciting current. This distorted current-wave can be resolved into third harmonic components which may, for certain combinations of transformer connections, result in third harmonic potentials between three wires (regarded as one) and ground. For other connections, triple-frequency currents may circulate through a circuit made up of transmission wires and ground.

The symmetrical construction of field poles and winding of alternating-current generators causes positive and negative waves to be of the same shape, and hence free from evenly numbered harmonics.* These even harmonics, nevertheless, may be introduced into a power system if transformers or other pieces of apparatus contain iron which is permanently magnetized. Ordinarily, transformers are free from permanent magnetism, but in circuits involving earth return there may be a considerable direct current passing through the windings, derived from neighboring direct-current trolley systems, etc., Oscillogram, Fig. 16 shows the exciting current in a transformer which has, at the same time, direct current in its windings. The general tendency in such cases is for the waves to be peaked and flat topped in succession.

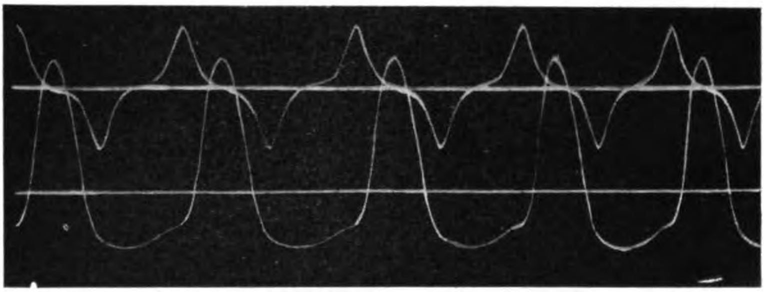


Fig. 16—Oscillogram, exciting current in 75-kw. transformer with direct current in winding. Upper curve: e.m.f. on transformer. Lower curve: exciting current

Even where the generated electromotive force wave is comparatively free from harmonics, the various pieces of apparatus on the system will all have their effect on the potential wave. An instructive experiment on this line is to connect a telephone

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* See " Even Harmonics in Alternating Current Circuits," Proceedings A. I. E. E., July 1909, pp. 963–970.

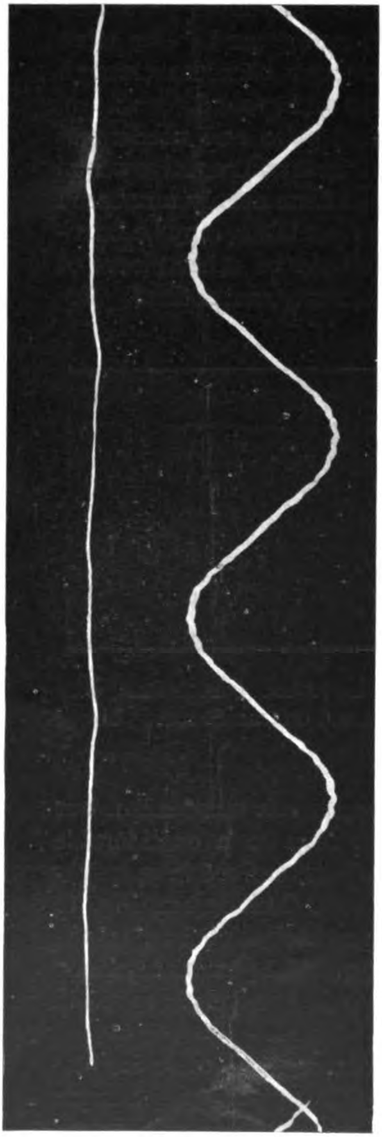


FIG. 17A

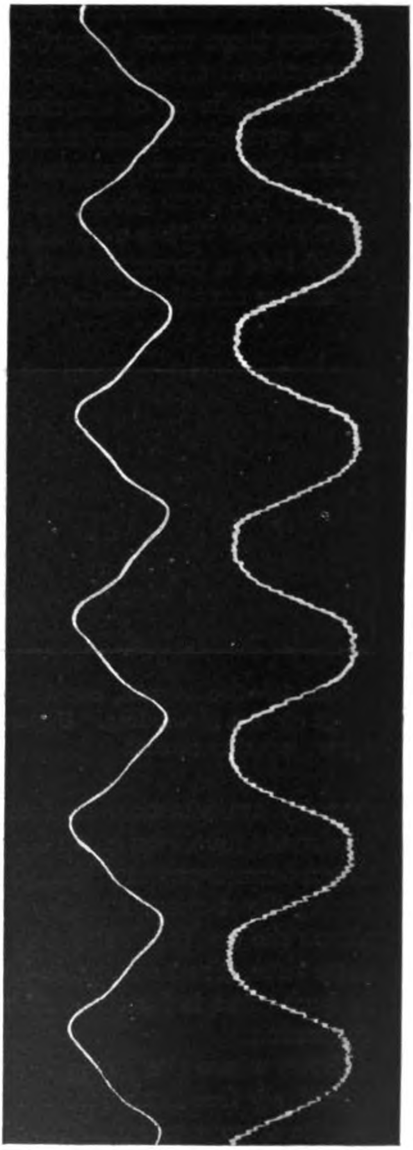


FIG. 17B

receiver in series with a small condenser, to alternating-current house-lighting mains. The number of strange noises heard in such a case, due mainly to induction motors on the system, will be a surprise to any one who has not tried this simple experiment.

Oscillograms in Fig. 17, show electromotive force waves on a single-phase trolley system under no load, and when commutating series single-phase motors are in operation.

Oscillograms Fig. 18 show the charging current between telephone line and ground, the same being in proximity to a single-phase trolley wire. Curve *a* is the charging current between the telephone line and ground with cars at standstill, and Curve *b* with cars in operation.

On account of the much greater sensibility of the telephone receiver to sounds of high frequency, these irregularities in the potential wave, although of much smaller magnitude than the fundamental frequency, are much more likely to be heard in neighboring telephone lines, when transpositions and other points of balance have not been given close attention. A condenser connected between alternating-current wires and earth, will, to a certain extent, absorb these high-frequency irregularities.

It should also be noted that the various neutralizing connections later discussed, as well as neutralizing for the fundamental frequency will, to some extent neutralize also for higher frequencies.

Single-phase railway. The several typical diagrams of Fig. 19 show the transformation and distribution arrangements for the latest addition to the alternating-current field—the single phase railway.

Diagram A shows the single-phase system in its simplest form. One terminal of a single-phase generator is connected to earth and the other to an overhead trolley conductor. The return circuit is made up of steel rails and earth. Neglecting line drop, the overhead conductor is at the same potential throughout and there being no neighboring conductor of opposite polarity, there will result electrostatic fields of constant strength irrespective of number of cars in operation. From the standpoint of inductive disturbances, this is the worst arrangement that can be made with the single-phase railway system. Electromagnetic effects will be proportional to the length of transmission and to current, and vary with load and distribution of cars.

Diagram B is just as bad electrostatically, but by locating the generating station at the middle of the line, instead of at the

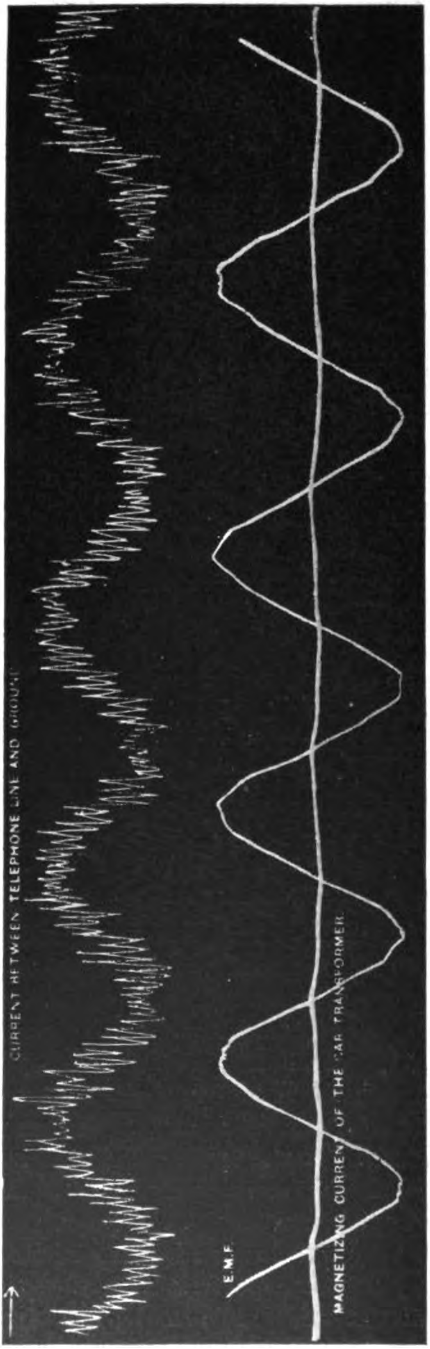

CURRENT BETWEEN TELEPHONE LINE AND GROUND
E.M.F.
MAGNETIZING CURRENT OF THE CAR TRANSFORMER

FIG. 18A

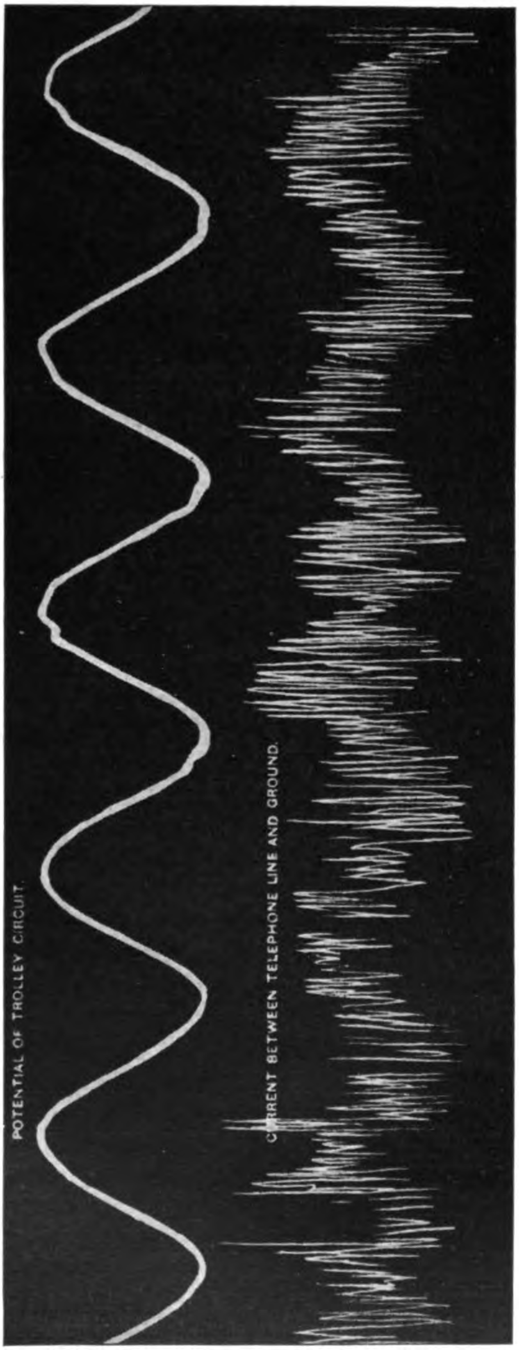

POTENTIAL OF TROLLEY CIRCUIT.
CURRENT BETWEEN TELEPHONE LINE AND GROUND.

FIG. 18B

end, the maximum length of feed is reduced to one half, and, depending on the running schedule of the cars, there may be a still further reduction in magnetic inductive effects through more or less neutralizing action from currents in opposite directions, to supply cars each side of the generating station.

Diagram C is an extension of B through the addition of transmission line and transformer sub-stations. Again considered from an inductive standpoint, this is better than B only through the feasibility of reducing the length of the individual sections. Diagram D is essentially the same as C except that transformer connections have been so made that alternate sections are of opposite polarity. Consequently, the equal exposure of a telephone or telegraph line to the same number of positive and negative sections will practically neutralize the effects of electrostatic induction. In this connection it should be noted that there will be charging currents flowing back and forth in a neighboring telegraph wire from the portion opposite the section of single-phase trolley of one polarity, to the neighboring section of opposite polarity. If there be intermediate stations on the telegraph line, these charging currents, flowing from one section of the wire to the other, may be sufficient to disturb the relay. From a railroad point of view, a section of trolley wire fed from a single sub-station is liable to tie up the whole road if a single sub-station goes out of commission. The circuit arrangement next to be considered obviates this difficulty by the use of trolley section continuous between sub-stations, thus giving duplicate feed.

Diagram E shows a typical arrangement of a single-phase trolley wire continuous between transformer sub-stations. In this arrangement all trolley sections are of the same polarity with corresponding electrostatic effects. From the standpoint of electromagnetic induction, however, this system of distributing has marked advantages. Assuming equal transformer potential at two adjacent sub-stations, a car midway between stations will draw equal current from the two sub-stations. These equal currents flow equal distances but in opposite directions, with a consequent neutralization of the electromotive force induced in neighboring telegraph or telephone wires. This neutralization also holds for positions of the car when other than at the half-way point, for while greater current will flow from the nearer sub-station, this greater current flows through a shorter length of trolley wire than does the lesser current from the farther sub-station.

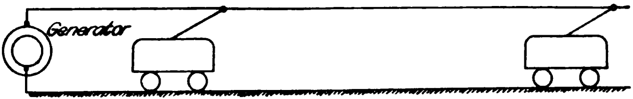
The next step is to combine the two arrangements as shown in diagram F, where trolley sections are fed from both ends, and alternate sections are of opposite polarity. This arrangement requires either two transformers at some of the sub-stations, or, what amounts to the same thing, a transformer with two secondary windings.

In the various distribution schemes already discussed, the neutralizing action, if any, is the differential effect between two or more sections. At any given point there is no neutralizing action, either electrostatic or electromagnetic. Consequently these arrangements are effective only where a telegraph line runs parallel to a number of sections at approximately the same distance.

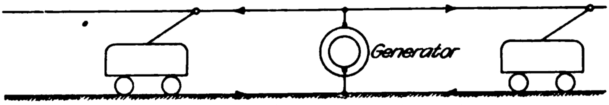
While it would be possible, it is by no means easily practicable to have a double-trolley, single-phase railway system; and, considered inductively, such a system would be on a par with any of the other metallic-circuit, alternating-current systems.

The various distribution arrangements for a single-phase railway, as shown in Fig. 19 and just considered, require no additional conductors, although the transformer sub-stations to accommodate the special arrangements may be an added item of expense.

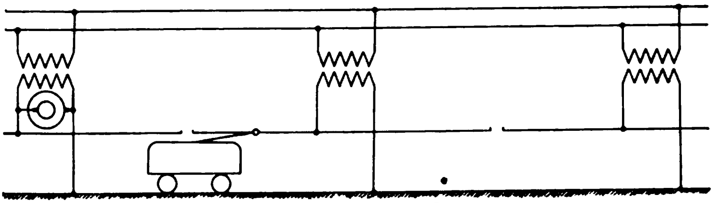
We will next consider the several distribution arrangements requiring additional conductors. Fig. 20 shows several schemes of distribution designed more or less to represent metallic circuit conditions, still retaining the single trolley. Diagram A shows a potential-neutralizing conductor erected in proximity to the trolley wire. By means of one or more transformers, this wire is maintained at approximately the same potential to ground as the trolley wire, but always of opposite polarity. Such a conductor will neutralize the electrostatic fields. It is more or less obvious that this neutralizing conductor might be placed nearer to a telegraph line than is the trolley wire, in which case a proper transformer ratio could be selected to neutralize the potential at the position of the telegraph wires. Such an arrangement, however, would be most effective for a single line of telegraph and would involve either extensive calculations or experiments to insure the best results. By having the neutralizing wire as close as possible to the trolley wire, no calculations or experiments are necessary, and the same wire will neutralize equally well for various telegraph lines, even if on opposite sides of the track and at various distances.



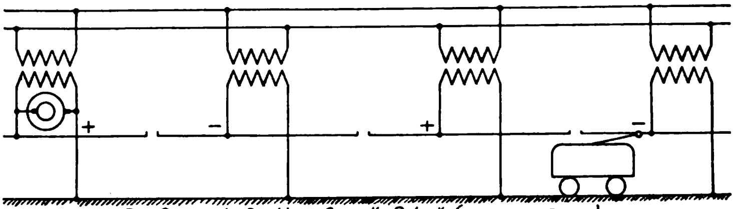
A Feed from One End



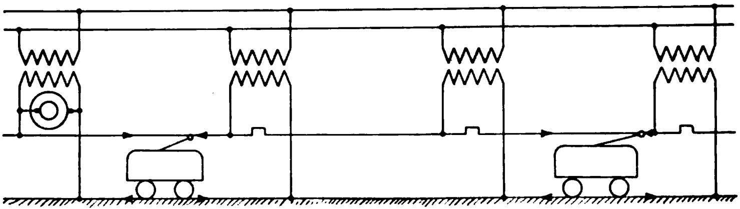
B Direct Feed, Generator at Middle of Line



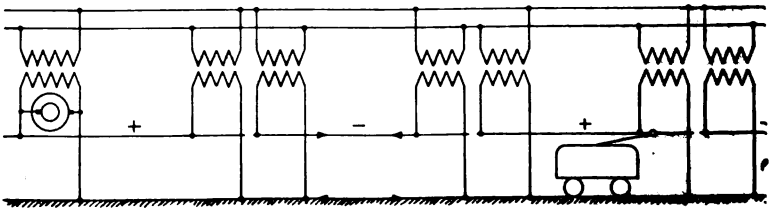
C Separate Sections, Same Polarity



D Separate Sections, Opposite Polarity (Electro-static Balance)



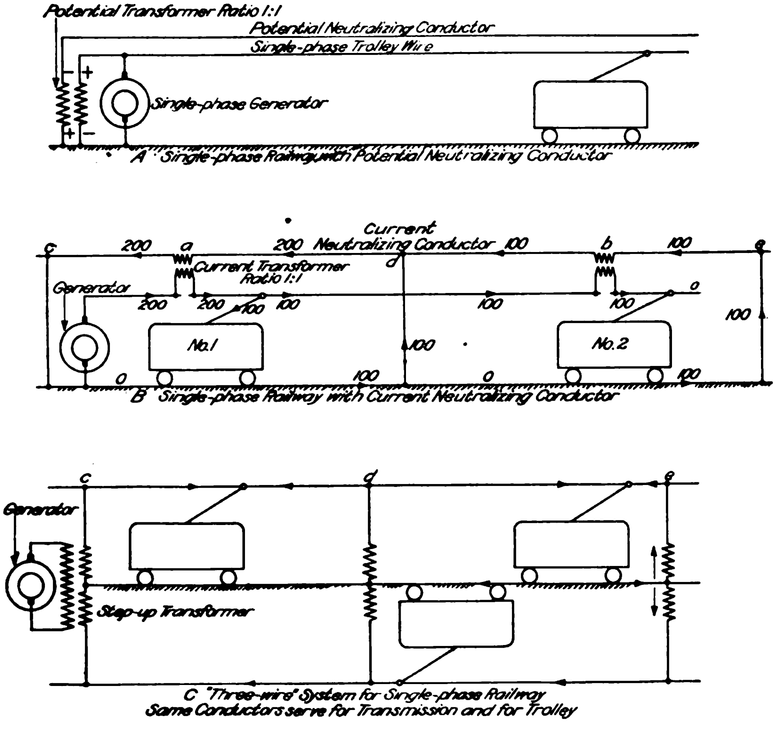
E Electro-magnetic Balance



F Electro-static and Electro-magnetic Balances

FIG. 19.—Distribution System for Single-phase Railway.

Diagram B shows a current neutralizing conductor in proximity to a trolley wire. This conductor must be of the same carrying capacity as the trolley wire, and current transformers, ratio 1:1, are cut into the trolley wire and neutralizing conductor at intervals. Midway between these transformers the neutralizing conductor is connected to the rail. The purpose of this scheme is obviously to cause equal currents to flow in opposite directions in the trolley wire and neutralizing wire. For certain positions of the cars, the neutralizing action will be insufficient: for other positions of the cars, an over-neutralized condition will result. By using a number of transformers, approximate neutralization may be obtained. The objection to this and similar arrangements is the extra expense of the neutralizing conductor and transformers, and the greater chance of shutdown due to the quantity of high-tension apparatus distributed along the line. As against the expense of the extra conductor it should be noted


Potential Transformer Ratio 1:1
Potential Neutralizing Conductor
Single-phase Trolley Wire
+
−
Single-phase Generator
Current Neutralizing Conductor
c
200
a
200
100
b
100
e
Current Transformer Ratio 1:1
d
Generator
200
200
100
100
100
100
0
100
No.1
100
No.2
0
100
0
100
c
d
e
Generator
Step-up Transformer

A Single-phase Railway with Potential Neutralizing Conductor

B Single-phase Railway with Current Neutralizing Conductor

C "Three-wire" System for Single-phase Railway
Same Conductors serve for Transmission and for Trolley

FIG. 20.—Neutralizing Conductors for Single-phase Railway Distribution.

that such a circuit will have small self-induction as compared with the usual single-phase circuit with overhead conductor and earth return. The inductive drop will therefore be considerably less, which may be an important factor in some cases.

By installing a potential-neutralizing conductor as described in diagram A, and a current-neutralizing conductor as well, metallic circuit conditions are approximated. A single current-neutralizing conductor of sufficient carrying capacity might serve for trolley wires over two or more tracks, and similarly,

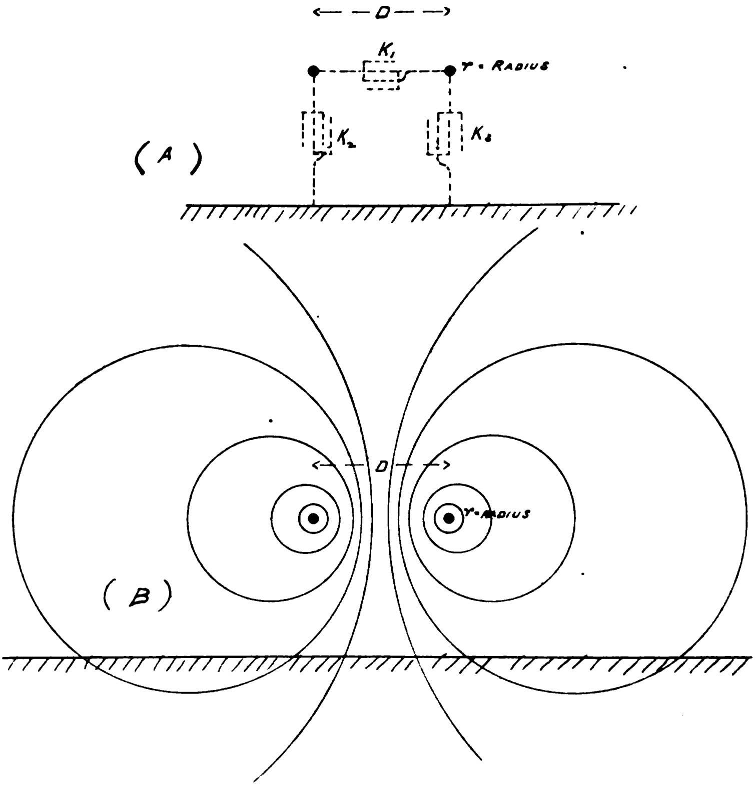


FIG. 21—The usual formula for capacity between wires is

$$C_{m.f.\ per\ mile} = \frac{0.01942}{\log_{10} \frac{D}{r}} \quad \text{(Diagram A.)}$$

This neglects effect of capacities to earth K_2 and K_3

The usual formula for inductance of a 2-wire circuit is

$$L_{m.h.\ per\ mile} = 0.0805 + 0.741 \log_{10} \frac{D}{r} \quad \text{(Diagram B.)}$$

This formula neglects the fact that some of the magnetic flux cuts the earth.

single potential-neutralizing conductor might serve for more than one trolley wire, either by increasing its size or the voltage supplied to it.

Diagrams C and D show arrangements where the same conductor tends to neutralize for both current and potential. Looked at from one point of view, these arrangements are similar to the Edison three-wire system, the rail return being the neutral. Compensators, or 1:1 transformers, keep the two conductors at equal and opposite potentials from earth, and the second conductor may or may not be used as a trolley wire. In the case of a double-track road, both conductors could advantageously be used as running conductors. 1:1 current transformers interconnecting the two conductors cause equal and opposite currents to flow in the two conductors, similar to arrangements in diagram B. Diagram D is the same as C without the current transformers, and this arrangement can be regarded as a high-tension transmission system of double the working trolley voltage. The transmission conductors thus form two working trolley conductors with neutralized electrostatic effects, and partly neutralized electromagnetic effects.

Calculation of inductive disturbances. While plenty of formulas for calculating self-induction, mutual induction, and capacity of circuits are readily available in handbooks and text-books, the practical cases in which we are interested are, in general, very complex, on account of the number of wires at different and unknown potentials, varying distance from ground, varying distance from disturbing wires, etc. In general, a calculation of inductive effects can be taken only as showing the proper order of magnitude. Where the earth forms one side of the circuit, it is usual to assume that the earth, right up to the surface, acts practically as a perfect conductor. Again, other formulas dealing with metallic circuits neglect entirely the effect of the earth, which, to be consistent with the other formulas, should still be regarded as a perfect conductor in proximity to the wires under consideration. For example; consider Fig. 21.

Let diagram A represent two conductors whose capacity is to be determined. This is given by the formula:

$$C_{m.f.\ per\ mile} = \frac{0.01942}{\log_{10} \frac{D}{r}}$$

It should be noted, however, that this formula, although that ordinarily given, does not take into account the added capacity due to the proximity of the earth. This added capacity may be regarded as composed of two condensers in series, as indicated. Where the two wires are comparatively close together, and a considerable distance from the earth, this additional effect may be neglected, but as the distance between the conductors is increased the effect of the earth may predominate.

Similarly in Diagram B, consider the self-induction of the circuit made up of two conductors. The self-induction is proportional to the magnetic flux included, but it is apparent that some of this flux will pass through the earth, which still being regarded as a more or less perfect conductor, will circulate eddy currents, which in their turn set up counter-flux, thus making the self-induction of the circuit lower, the nearer the wires are to the earth. Therefore, any formula for capacity or inductance which takes no account of the relative position and conductivity of the earth must be regarded as approximate only.

The purpose of this paper is not to develop methematical formulas for the various combinations of alternating-current power circuits and telephone and telegraph circuits, under conditions which might be more or less realized in practice. As soon as we have to deal with more than three or four conductors, the formula becomes so complicated as to be practically unmanageable. This, taken with the fact previously stated, that all these formulas depend upon assumptions as to conductivity of the earth, etc., not actually realized, and which are unknown quantities, makes it appear preferable to present two or three typical formulas and curves for simple cases, leaving the calculation of complex circuits to those who delight more in mathematical exercises than in experimental determinations of values.

We must make some assumption regarding the conductivity of the earth, and the path taken by return current in the earth. In the usual formulas for capacity and inductance of circuits the assumption has been made that the earth acts practically as a perfect conductor. This assumption appears to be sufficiently exact, as far as the electrostatic effects with which we are interested are concerned, since the wires are usually at distances of about 20 ft. from the earth, so that the charging currents are relatively small. Even high resistance at the earth's surface could cause the potential at the surface of the earth, beneath the wires, to differ but very slightly from true " earth " potential.

Return currents in the earth, however, are of an entirely different order of magnitude, so that the path taken by this return current will tend to be that which offers the least resistance. This return path of lowest resistance will be modified by the fact that the farther the return circuit from the overhead wire, the greater will be the inductive drop, which, in its turn, will tend to cause current to flow nearer to the line conductor. The actual or effective return, therefore, will be

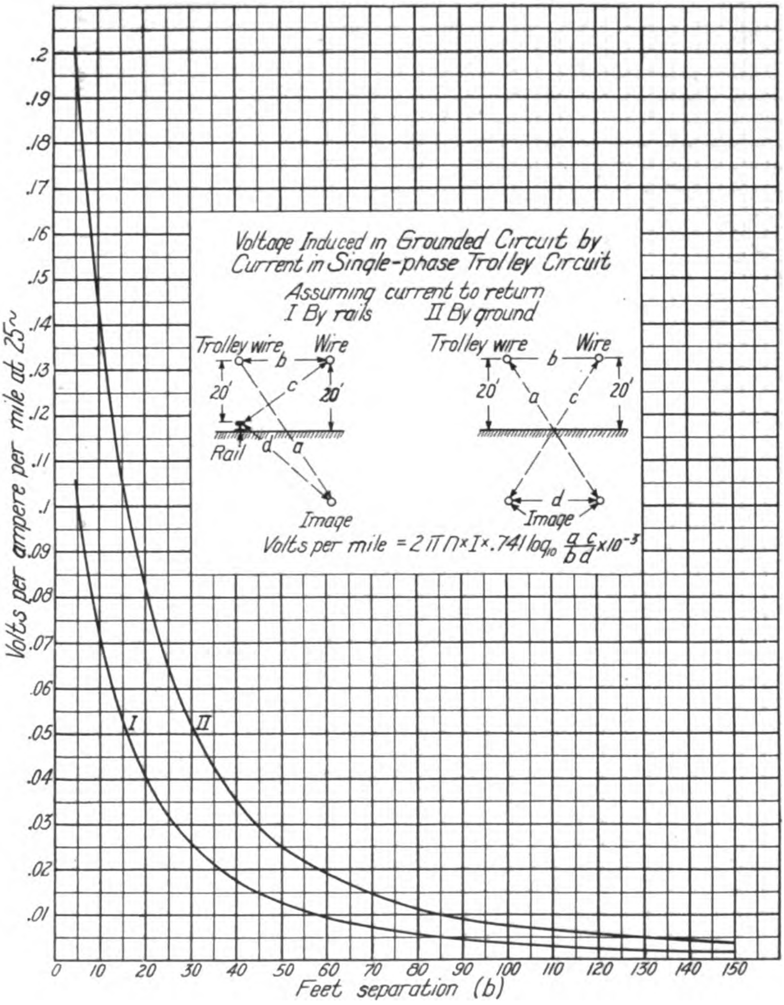


FIG. 22

determined by a combination of resistance and inductive effects, in a given case depending largely on nature of soil, amount of moisture at different depths, proximity to bodies of water,

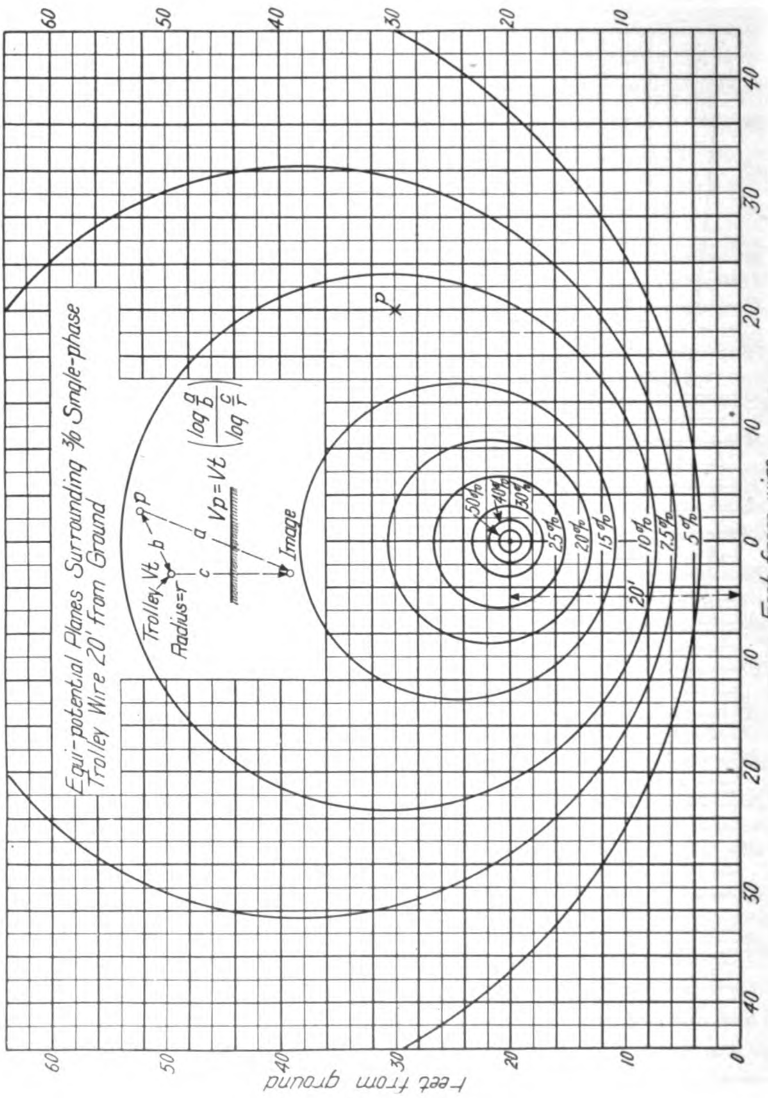

Equi-potential Planes Surrounding 3/0 Single-phase Trolley Wire 20' from Ground
Trolley Vt
Radius=r
P
b
a
c
$V_p = V_t \left(\frac{\log \frac{a}{b}}{\log \frac{c}{r}} \right)$
Image
P
50%
40%
30%
25%
20%
15%
10%
7.5%
5%
20'
Feet from wire
Feet from ground
60
50
40
30
20
10
0

FIG. 23

water mains, gas mains, and rails of neighboring traction systems.

However, in order to deal at all with the question, it is necessary to make one assumption or the other; either that the earth is an insulator or a perfect conductor. The various formulas are based on the latter assumption. With this assumption it can be shown that the effect of distributed charge or current is the same as though this charge or current were concentrated on a wire as far below the ground as the wire in question is above the ground; in other words, on what would be the "image" of the overhead conductor if the surface of the earth formed a mirror. This means that where the earth forms a return cir-

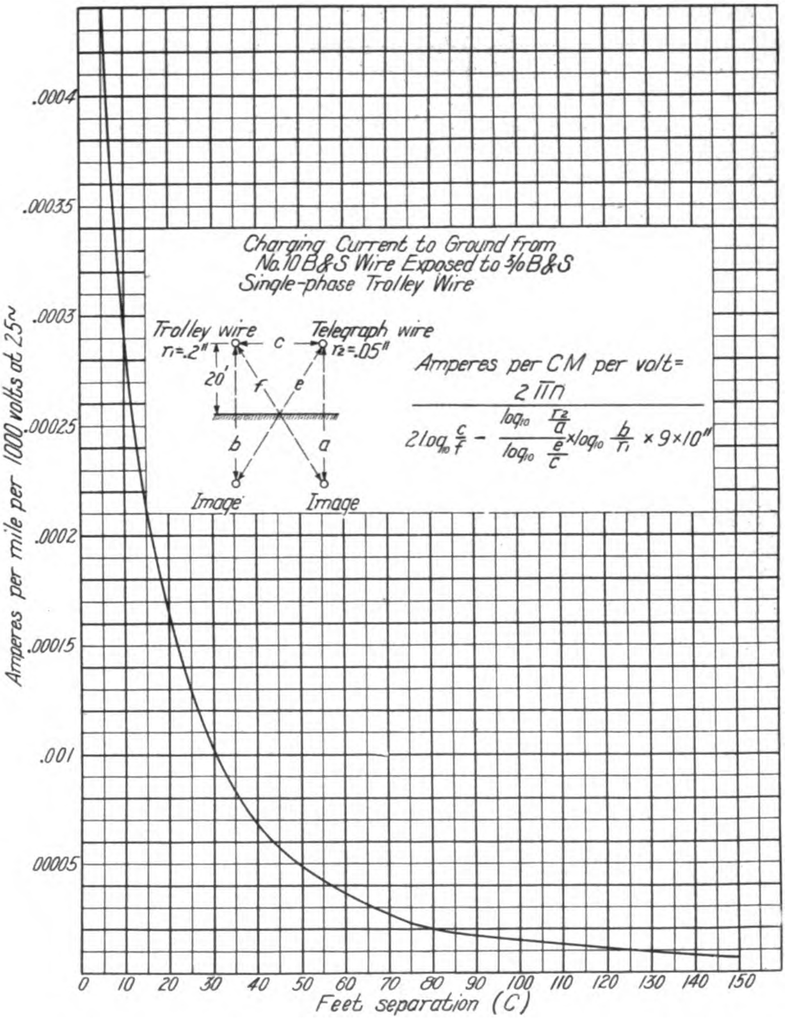


FIG. 24

Errata: Ordinate .001 should be .0001.

cuit to a conductor 20 ft. in the air, the effective separation of the two conductors, and hence the self-induction, will be that corresponding to a two-wire circuit with conductors 40 ft. apart instead of 20 ft. apart.

In calculating the inductive effects from a single-phase railway, we may, on the one hand, assume that all of the current returns by way of the rails, which will lead to too low inductive values, as some of the current is almost certain to leave the rails and return by way of the earth. On the other hand, the image assumption may also lead to too small inductive values on account of the imperfect conductivity of the earth. The

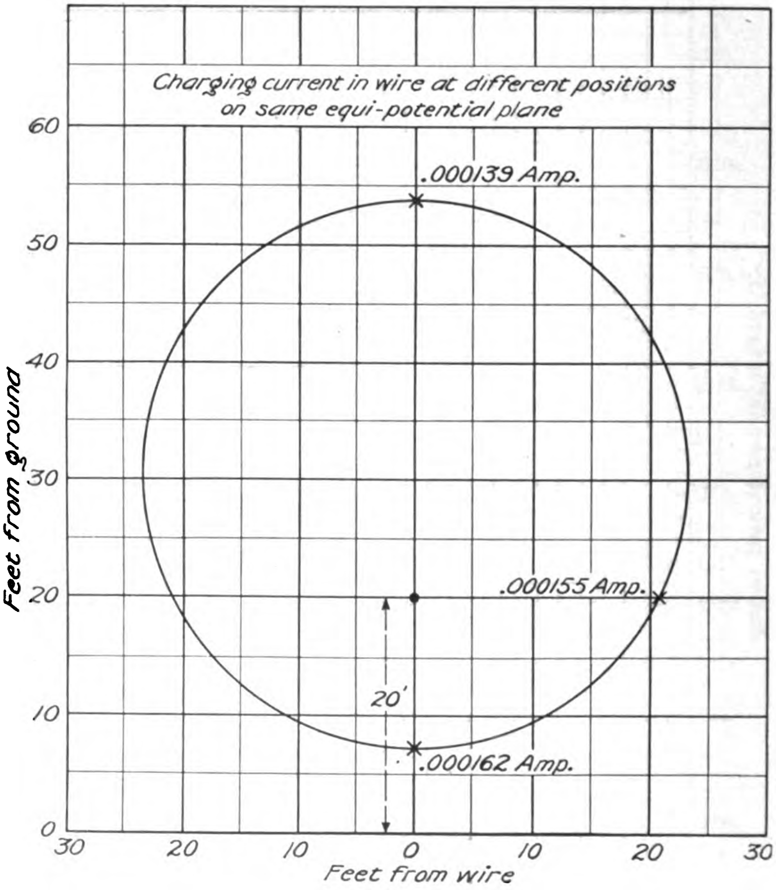


FIG. 25

true inductive value, therefore, will be influenced by the amount of current leaving the rails, and also on the effective path taken by this current. In the absence of definite experimental determination of inductive action in and from a given circuit, we may assume the image as the effective return conductor.

The electrostatic potential at any point depends on the relative positions and charges of other conductors in the neighborhood. The charging currents, therefore, flowing into a grounded wire will not be the same when it occupies different positions, even though the potential on the wire when insulated is the same for the different positions considered. This is because of the reaction of the induced charge. For example, Fig. 26 is taken from Fig. 23, and the circle represents the 10 per cent potential surrounding the 000 trolley wire 20 ft. from the

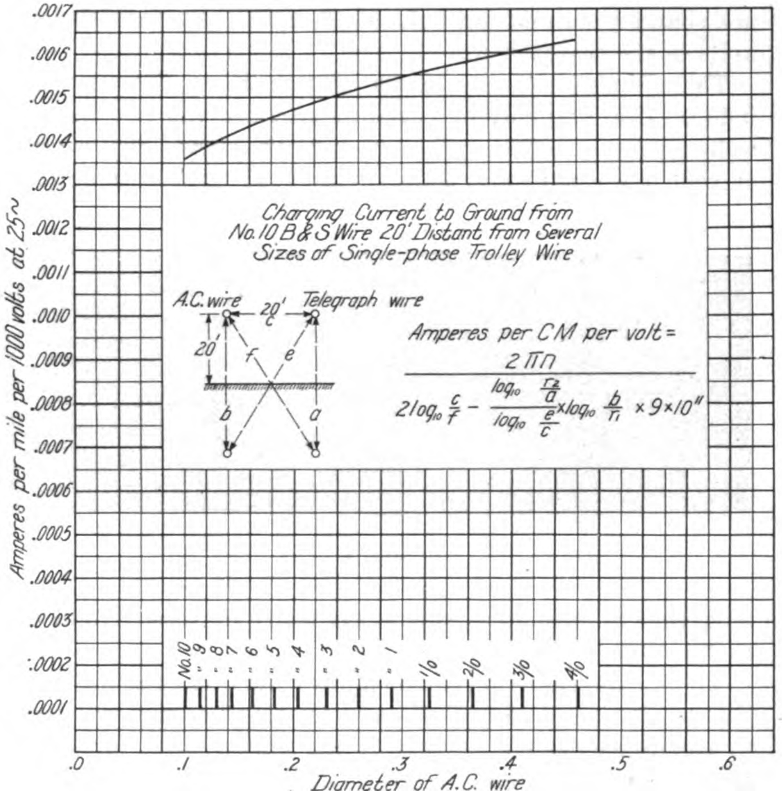


FIG. 26

ground. A wire occupying any position on this circle would show the same potential to ground, if measured by an electrostatic voltmeter. However, the charging current when the wire is grounded will vary for different positions on the circle. This charging current will be a maximum when the wire in question is directly below a disturbing wire, and a minimum at the position directly above, and for other positions will have some intermediate value. The figures against three positions are charging current per mile at 25 cycles for each thousand volts of the trolley wire.

The effect of a change in size of wire on an electrostatically induced charging current is slight, provided the two wires are well separated. The curve in Fig. 25 shows the charging current in a No. 10 wire 20 ft. from a 0000 trolley wire, and the reduction in current as this is gradually decreased from 0000 to No. 10 B. & S.

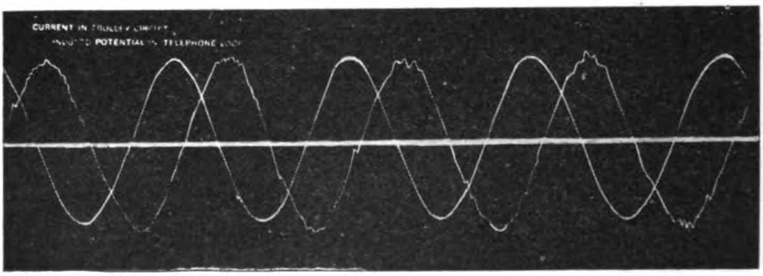


Fig. 27

VI. *Comparison of electromagnetic and electrostatic effects.* The resulting disturbances in any telegraph circuit will be due to electromagnetic and electrostatic effects; that is, the two factors must be combined vectorially, the angle of this combination depending on the power-factor of the load and various constants of the telegraph circuit. Oscillogram Fig. 27 shows current in a single-phase trolley circuit, and electromotive force induced thereby in a neighboring telegraph loop. The high-frequency irregularities on the induced wave are due to the addition of electrostatic effects. The current in the circuit due to electromagnetic induction will obviously be a maximum when all the keys are closed. An electrostatic charge will flow in from both ends of the line when all keys are closed; under other conditions this charge must all be supplied from the ground at one end of the line. It should be obvious, therefore, that the nature of the disturbance experienced will depend on whether electromagnetic or electrostatic induction is the predominating factor. Below are given in parallel columns some of the features of electromagnetic and electrostatic inductive effects.

TABLE I

Electromagnetic	*Electrostatic*
Varies with load.	Constant effect.
Varies with position of car.	Independent of position of load (neglecting line drop).
Induced electromotive force in proportion to frequency.	Open circuit potential (to ground) independent of frequency. Charging current if grounded, in proportion to frequency.
Induced electromotive force proportional to length.	Open circuit potential (to ground) independent of length.
Current in closed telegraph line practically independent of length. (Assume total impedance increases proportional to length.)	Charging current, when grounded proportional to length.
Induced current in instruments greatest when all keys are closed.	Charging current in some instruments greatest when distant key is open.
Practically same current in all instruments.	Current a maximum in some instruments, while zero in others.
Line resistance and reactance an important factor limiting current.	More in the nature of a constant current effect.
Generally the predominating effect in telegraph lines.	Generally the predominating effect on telephone lines.
Slight shielding action obtained from neighboring conductors.	More effective shielding action from neighboring conductors.
Part shielding obtained by placing in lead-sheath cables, or by placing underground.	Effective shielding by use of lead sheath cables.

SUMMARY

All working conductors are surrounded by electromagnetic and electrostatic fields. These fields induce electromotive forces and charges in neighboring conductors. With an ideal metallic circuit, external fields are a minimum. Similarly, an ideal metallic circuit may be in fields of any strength without being disturbed.

Practical considerations prevent these ideal conditions from being realized. Hence currents will be induced in any conductors wherever placed as a result of currents and potentials on other conductors. Disturbance results only when these induced currents are of sufficient magnitude to be objectionable.

Commercial telephone lines have little margin to meet disturbing conditions more severe than normal. An increase of telephone currents to three or four times their present values would doubtless result in great disturbance to other wires in the same telephone system and require new standards of construction and maintenance. The same statement applies to telegraph systems.

Theoretically a balanced telephone line can be operated in proximity to alternating-current wires. This is not true of a telegraph line, as there is no way of balancing a circuit using earth return.

Where trouble is experienced on a telephone line it may be possible to clear same by putting the system in first-class condition. Where trouble is experienced on a telegraph line, some change in the apparatus or circuit arrangements will be necessary.

For any given case, all the features of the power system and signaling system should be taken into account with a view to arriving at the proper procedure to reduce or to eliminate the disturbances.

DISCUSSION ON "LOSSES, INDUCED VOLTS AND AMPERES IN ARMOR AND LEAD COVER OF CABLES." FRONTENAC, N. Y. JUNE 29, 1909.

(*Subject to final revision for the Transactions.*)

Ralph D. Mershon: Once I asked Mr. Fisher to make some measurements on three-conductor, three-phase cables, measurements which would show whether there were any losses in the lead sheath. I knew of a case where some three-conductor cables showed after installation higher losses and higher drops than the calculations had indicated. I do not remember the results of these measurements and it will be interesting to hear them in connection with this paper.

H. W. Fisher: I made tests to determine the lead and copper losses due to eddy currents in a piece of 500,000 cir. mils lead-covered cable. First of all, the total losses were measured and the $I^2 R$ losses subtracted to get the total eddy-current losses. Then the lead cover was removed and the same test repeated to obtain the eddy-current losses in the conductor. The frequency was 60 cycles. The total eddy-current loss was 13 per cent of the $I^2 R$ loss, and was divided as follows; lead loss 6 per cent; copper loss 7 per cent.

John B. Whitehead: Mr. Fisher has spoken of the advisability of putting all the conductors into one sheath wherever it is possible. There is one class of circuit—an instance of which led to the paper which I gave this morning—in which there is necessity for insulating only one side, the case of a single-phase trolley carried through a drawbridge. It is unnecessary to insulate the grounded conductor. Double-conductor cables cost 50 per cent more, and by putting in single-conductor cables more may be put in for the same money and additional reserve capacity obtained. The reactance of short lengths is no difficulty, nor are the losses great enough to cause trouble.

Charles P. Steinmetz: This paper brings out strongly the fact that in steel-armored, single-conductor cables we may get heating and effective resistance and impedance many times greater than that corresponding to the conductor copper. It also brings out the fact that the increase of effective resistance and impedance cannot be expressed in any simple manner, but varies over an enormous range for changes of current with changes of arrangement, with the manner and character of applying the steel armor, etc. Incidentally, this impedance curve of the cable has a close similarity to the permeability curves of iron, as is to be expected. It therefore appears to me that the single-conductor, steel-armored cable is unsafe to use, and should be avoided as far as possible; where it is used, it is not safe merely to make a few measurements and tests of impedance and resistance to determine its probable behavior, but the investigation must be extended over the entire range of operating conditions which the cable may meet under normal as well as abnormal conditions of service. I would rather use two-conductor cable even if unarmored. With single-conductor cables of higher voltages, in addition to the phenomena of losses, and possibly related to them, there appear a number of very high frequency disruptive effects, some of them unexplained, which have in a number of instances of station wiring led to the abandonment of armored cables, and even of lead-covered, single-conductor cables in favor of unarmored cables. I believe, in general, the conclusion is that a single-conductor cable, whether lead sheathed or steel armored, is not safe in electrical systems.

J. B. Whitehead (by letter): Consider a double-conductor submarine armored cable connected for carrying the track and trolley circuits across a drawbridge. The conductor in the track circuit has in parallel with it all possible ground paths between the two sections of track on opposite sides of the draw. The track is usually well grounded at such points, either by the bridge and supports or frequently by intention by means of ground plates in good water bottom. A steel cable or a chain is also often installed as a protection against dragging anchors. The armor and lead cover of the cables also contribute their conductivity. If all these grounded circuits are tied in together it is not difficult to imagine a considerable diminution if not extinction of current in the track conductor of the cable. The cable thus operates more or less completely as a single conductor concentric cable, and it would be difficult to prevent its doing so.

Three single-conductor armored cables 200 ft. long have been in service in the trolley circuit of a 6600-volt, single-phase road for over a year, under widely varied conditions of load and have given no evidence of trouble.

DISCUSSION ON "CORONA PHENOMENA IN AIR AND OIL AND THEIR RELATION TO TRANSFORMER DESIGN."

FRONTENAC, N. Y., JUNE 29, 1909

(Subject to final revision for the Transactions.)

John B. Whitehead: I wish to say a word about the sentence which reads as follows:

> From a number of experiments the maximum permissible stress in air at atmospheric pressure seems to be 100,000 volts per inch.

Dr. Steinmetz has sometimes placed this figure as high as 120,000 volts. Mr. Berg used 100,000 volts in one of his Institute papers; also in his book "Electrical Energy", in which he included a table giving the calculated values at which transmission lines may be expected to discharge between wires. There is a wide discrepancy between the calculated values given by Berg and those observed by Mershon, in fact Mershon's values are 30 per cent lower than those calculated by Berg. I have figured this discrepancy for two cases. Berg gives a figure of 104,000 volts approximately for one of the cases investigated by Mershon, whereas Mershon's value lies between 62,000 and 74,000 volts, according to the vapor product. In another case Mershon gives 42,000 and Berg 60,000 volts. Mr. Moody finds that the values he observed are even higher than the calculated values using 100,000 volts as the intensity at which air may be expected to break down. He is, therefore, further than Berg from Mershon's values. All of these conclusions are on the assumption that Mershon's critical point is the point at which the corona becomes visible. I understand this is true, although I should like to have it confirmed. At any rate, we now have quite a discrepancy, about 50 per cent, in values of voltage at which discharge takes place.

In beginning some work on this subject, I have recently had occasion to calculate the potential gradient necessary to start corona discharge, with various assumptions as to the nature of the phenomenon. J. J. Thomson has developed a theory of spark discharge. The experimental results have shown that one cannot get a spark in air at any pressure at a lower value than about 350 volts, and moreover at atmospheric pressure 0.01 of a millimeter is the shortest gap for this voltage. There is a constant minimum spark potential and a minimum spark length dependent on the pressure. Applying Thomson's theory to the case of transmission lines, we find it will not serve, for the value at which the air in the vicinity of the wire may be expected to break down, according to this theory, works out to be about 500,000 volts per centimeter.

Taking another theory as to the nature of the phenomenon; Hobbs has shown that corpuscles or elementary negative charges may be drawn from the material of the wire at a potential gradient corresponding to 100 volts acting over 10^{-4} cm. Applying this to the potential gradient in the vicinity of the wire, which as calculable, we again find a value of different order of magnitude from that observed; namely, about 800,000 volts.

Townsend has shown that ionization by collision, which causes conductivity, will take place at lower values of potential gradient even than that necessary to start and maintain a discharge; and if we take his results, and those of Von Schweidler, we find 30,000 volts per centimeter indicated as the potential gradient at which the intensity is sufficient to start secondary ionization. As 30,000 volts per centimeter is about 75,000 volts per inch, I submit that the formulas and observations would be brought into better accord if 75,000 volts per inch were taken as the potential gradient at which air may be expected to break down in the neighborhood of conductors; and further that secondary ionization is the immediate cause of the breakdown.

One of the most interesting things in Mr. Moody's paper is the clearness with which he shows how sensitive the whole phenomenon of corona discharge is, how easily it is affected by the surrounding conductors, and the presence of metal or dielectrics in the field. The immediate effect upon corona of the manner in which the lead wires are brought in is most important. Mr. Moody suggests that perhaps his observed values differ from the calculated values because of the surrounding and shortness of his wire, and the proximity of neighboring conductors. I think this is also the probable explanation of the wide difference between his values and those of Mershon and others.

J. C. Lincoln: I ask Mr. Moody if he made any measurements at all of the energy required by the wire when it is in the condition of corona discharge? There is, doubtless, energy dissipated from the wire when the discharge is taking place. I also ask if any energy is dissipated by the wire at the potential just below the point at which the corona appears? The next paper to be presented speaks of one case where there is a difference of 1000 volts between the point where darkness is obtained and where the corona appears. Is any energy dissipated from the wire at the lower voltage? or is the difference between the disspiation of energy and the non-dissipation of energy as closely related as the appearance and disappearance of the corona?

Ralph D. Mershon: Dr. Whitehead and Mr. Lincoln have both raised a very interesting point which is touched upon by some information Mr. Faccioli sent me a few days ago. It is the question as to the relation between the critical point and the point at which corona discharge begins. Professor Ryan, I believe, came to the conclusion that they were identical. In my work I had no means of determining whether or not they were identical, because my investigation work was done on overhead lines in a place always more or less illuminated, arc lights some distance away, and the illumination was much too great to determine any corona effect. It would not have been practicable to have gotten in doors a sufficient length of line to measure the loss by the method of measurement I employed.

I have pretty nearly come to the conclusion that the two are not identical, that there has to be a considerable amount of loss before there is any visible manifestation. It would seem reasonable to assume that is the case; that an instrument would probably detect the critical point before the eye would. I feel quite sure that the critical point is affected by the conditions of moisture in the atmosphere, and the results I have obtained seem to show that there is a definite relation between that point and what I call the vapor product. On the other hand, Mr. Moody and Mr. Faccioli kindly endeavored, at my request, to find a relation between vapor product and corona, and were unable to find such relation. I was surprised that this should be the case, but after thinking it over have hit upon a possible explanation as to why there should be no relation between corona and variations of such atmospheric moisture as would ordinarily obtain. If the corona effect is a phenomenon of the air itself, which we assume it is, it is conceivable that the addition of moisture to the air would, up to a certain point, play a part comparable to that of a resistance in shunt to an arc. So long as the resistance is at a high value one will not be able to observe, usually, any difference in the behavior of the arc, but if the value of the resistance is progressively decreased the time will come when there would be an appreciable effect. Now, if the amount of moisture in the atmosphere is low enough, it seems to me it will not affect the corona at all, whereas if the atmosphere is heavily enough laden with moisture the corona may be affected.

I think the apparent discrepancy between my results and those of Professor Ryan and the authors of this paper is due to the fact that the critical point as we have been defining it is not coincident with the point at which corona is visible.

S. B. Charters, Jr.: Following out Mr. Moody's suggestion, or probably preceding his ideas, Professor Ryan has already built at Stanford University what he calls a corona voltmeter, which is used to indicate pressure by corona formation. It has a tapered brass rod inserted in a wire cylinder of uniform diameter and produces fairly reliable results. We have observed that it makes a difference in what manner the leading-in wires are attached. The instrument can be thrown out of calibration by bringing the leading-in wire at some other point than the one at which the calibration has been made. Our results in general are in agreement with Mr. Mershon's. The greatest use for this instrument has been in observing transient phenomena, because the corona will follow all sorts of variable phenomena such as the surging introduced by switching. This spring we incidentally checked, in a very small way, the results obtained by the addition of insulators to conductors; while we did not attempt to make any experiments, our results were in accordance with the results here obtained.

We tried a few experiments on corona under oil, getting results which agreed with the above. I wish to emphasize the point of the tremendous mechanical strains to which the oil and wire are subjected under these conditions. We used a No. 34 wire inside a 4-in. cylinder; and the vibration of the wire was sufficient, when under strain, to shake, not only the stands, but to move a weight of several pounds of iron. We moved the whole stand and iron bodily, simply by the vibration of the small wire under the static strains.

W. S. Moody: I think the only answer needed is to the question that Mr. Lincoln asked; that is, whether we attempted to determine the energy used in creating the corona, and whether we could distinguish between the power required to produce a visible corona and the power required for invisible corona, if such exist.

I tried to make it plain that we did not attempt to make any measurements of the power required to produce corona, for the reason that it was impracticable to erect within a dark room of any practical size sufficient highly insulated wire to get a loss from corona of such an amount as would be measureable with any ordinary wattmeter.

Harris J. Ryan (by letter): Through the facts brought out in this paper, the papers and contributions of Mershon, Watson, and others, we are now prepared to understand the practical significance of the conducting character of the normal atmosphere as determined and expressed by J. J. Thomson and other able physicists. They have found that the normal atmosphere contained in a closed vessel conducts a little even under the smallest electric intensities; *i.e.*, kilovolts per inch; that such conductivity is due to the total number of free ions mixed with the volume of air employed; that the origin of the free ions is due to some external ionizing emanations from the walls of the atmosphere container and the conductors employed or from the outer terestial solar or cosmic sources now known to be numerous; that the value of the current which the atmosphere will thus conduct increases, first regularly with the increase from zero of the electric intensity, then less in proportion until saturation is reached, when the current no longer increases as the electric intensity increases until a critical value is attained: whereas, if exceeded, the atomic structure of the atmosphere is broken, ionization extends from the electrodes and the current is increased at a greatly accelerating rate as the electric intensity is further increased, resulting in the formation of strong coronas or arcs dependent upon circumstances.

For the present purpose we may call the current which is due to the free ions mixed with the atmosphere the *free ion-loss current*, naming *corona-loss current*, that which is due to active ionization. The value of the free ion-loss current depends upon the total number of ions present in the volume of atmosphere employed. When the container is large the free ion-loss current will be large; again when the source of free ions is prolific, the free ion-loss current will be correspondingly great. It is reasonable to expect that with actual line conditions out of doors, because of the vastly greater atmospheric volumes and numerous sources of free ions, especially in great industrial regions, that the free ion-loss current would occur in far greater proportions, totally changing its characteristic relation to the initial corona loss current. At Ithaca in 1903-4, by the methods and under the indoor atmospheric conditions there employed, it seemed conclusive that the atmosphere losses are neglibibly small for clean conductors at pressures under the visible corona-forming values.

The earlier results of Mershon in the Rocky Mountains, of Harold B. Smith at Worcester, the results obtained at Ithaca, and the recent continuous current results obtained by Watson at Manchester, England, are in fair agreement as to this point. The more recent results obtained by Mershon at Niagara Falls are not in accord in this respect, and the cause may be due to the out-of-door character of that region. That is to say, the coincidence or non-coincidence of the electric intensities at which critical loss and visible corona occur may depend considerably upon local conditions; or, to put it another way, when conditions are such as to cause the free ion-loss current to be relatively large, the critical value of the loss current may possibly occur at a decidedly lower pressure than that which will start the visible corona.

As to the volts per inch at which the normal atmosphere is ruptured: J. J. Thomson is likewise authority for the value of 30,000 per centimeter at which active ionization occurs; this corresponds to 76,200, volts per inch. In the work at Cornell where the alternating pressures that short coronas on conductors having diameters ranging from 0.05 in. to 0.65 in. were found to produce an electric intensity in the atmosphere next to the conductor surface ranging from 190,000 volts per inch for clean conductors with diameter at 0.05 in. down to 90,000 volts per in. for conductor diameters of 0.65 in. All results, however, pointed to the correctness of an idea advanced some years earlier by Steinmetz; namely, that there exists a thin atmospheric zone adjacent to conductors that will endure greater electric intensities than the normal atmosphere beyond. A process was then found for locating the thickness of these zones beyond which the normal atmosphere would break first on the application of the corona forming electric intensity. The values of such critical electric intensities could then be estimated by the method illustrated in the following example:

Beyond the surface of a clean brass conductor 0.65 in. in diameter, the normal atmosphere broke into corona at a distance of 0.07 in., at a dielectric flux density of $170{,}000 \times 10^{-13}$ coulombs per inch cube. The coulomb per inch cube per volt established in the normal atmosphere are 2.244×10^{-13}.

It follows, therefore, that the volts per inch of electric intensity that ruptured the zone of normal atmosphere about this conductor was found to be

$$\frac{170{,}000\times 10^{-13}}{2.244\times 10^{-13}} = 75{,}700,$$

a value that is in accord with the authoritative conclusion of leading physicists and that submitted above by Dr. Whitehead. This value of 76,000 was obtained for all sizes of conductor from 0.65 in. down to 0.2 in.; below that the results gave an increase from,—what cause was not determined. It may possibly be due to the lack of free ions emanating from the surface of the small conductor, or to some related cause.

As to the corona voltmeter mentioned by Professor Charters. It was made about two and a half years ago and has been used so far only for lecture work. It is heartily recommended to those who want to observe transient phenomena on high-pressure circuits, by direct vision or through a revolving mirror, for it is really also a sort of corona oscillograph. At this writing I am compelled to give the dimensions of the instrument and its range from memory in order that this communication will be returned with the proof of this discussion within the prescribed limit. However, the values are throughout about right as given, because the recollection of them is clear.

The instruments consists of a tapered brass rod. 7 ft. long, ⅜ in. diameter at the larger end and uniform for 1 ft., then tapering uniformly, to a diameter of 1/16 in., at the opposite end. At the center of a 0.5 in. square galvanized steel wire net cylinder of the same length and 15.5 in. inner diameter, suitably insulated, the tapered rod is mounted. When put in the dark, and alternating pressure applied between rod and cylinder, the corona first appears at the small end of the rod, when ordinary barometric pressures and temperatures attain, at about 25,000 effective sine-wave volts and extends the length of the rod as the pressure is elevated, reaching its full tapered length at about 55,000 volts. For greater ranges the dimensions must be increased in proportion or instruments in this size must be balanced in series across the circuit. It has not as yet been used in work of investigation. However, for some such purposes it will be useful.

Discussion on " Surges on Cable Systems with Aluminum Cell Protection." Frontenac, N. Y., June 29, 1909

(Subject to final revision for the Transactions.)

J. L. R. Hayden: To investigate how the aluminum cell protects apparatus against high-voltage disturbances, a number of oscillograms were taken, some of which are given in the following.

A standard 5-kw. lighting transformer, shown in Fig. 1, was connected, with its low-potential coil as primary, to 60-cycle city supply of Schenectady, and high-voltage impulses were sent into the secondary . These high-voltage oscillations were produced by the discharge of a large mica condenser *C*, Fig. 1, through a series of reactive coils *X* and over a spark-gap *S*. An air-blast across the spark-gap *S* gave abruptness to the discharge. The reactance-*X* were chosen so large as to bring the frequency of the discharge—about 1000 cycles—well within the range of the oscillograph.

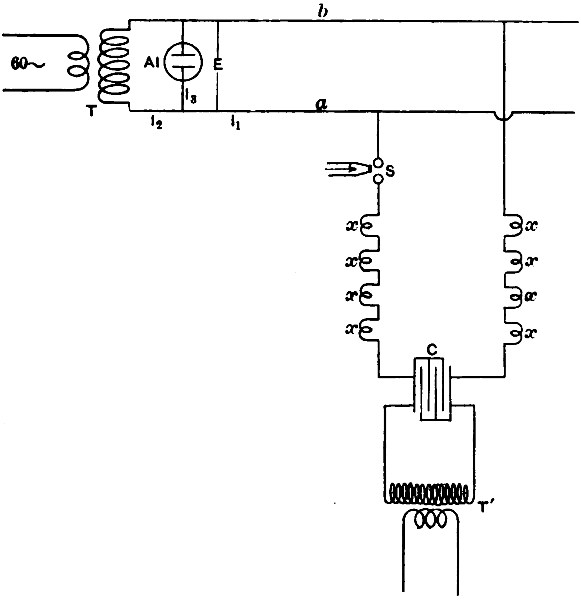


Fig. 1

The condenser C was charged by a 30,000-volt transformer T^1. As often as the voltage at the condenser *C* rises sufficiently high to break over the spark-gap *S* it sends an oscillatory discharge or high-voltage impulse into the line *a b* and the transformer *T*, the arrangement thus represents the condition of a step-up transformer continuously receiving high-voltage impulses from a transmission line (as by an arcing ground on the line).

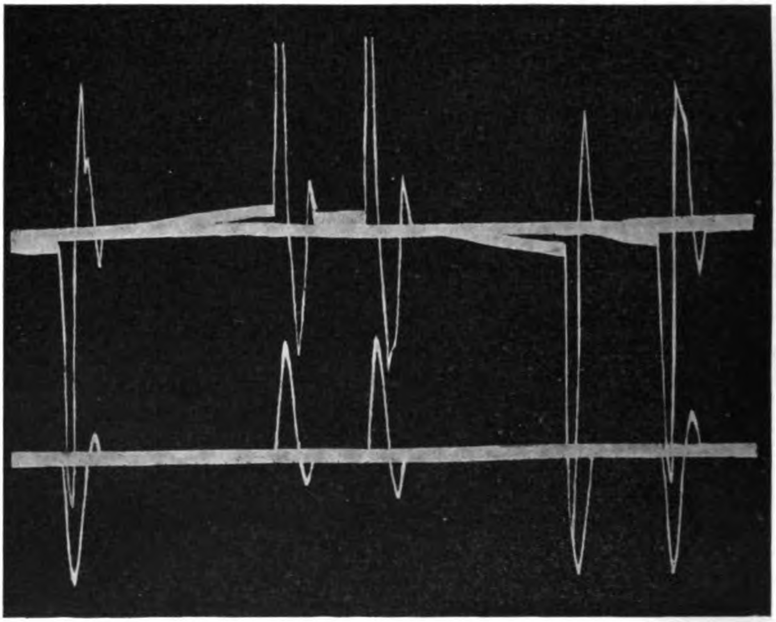


Fig. 2

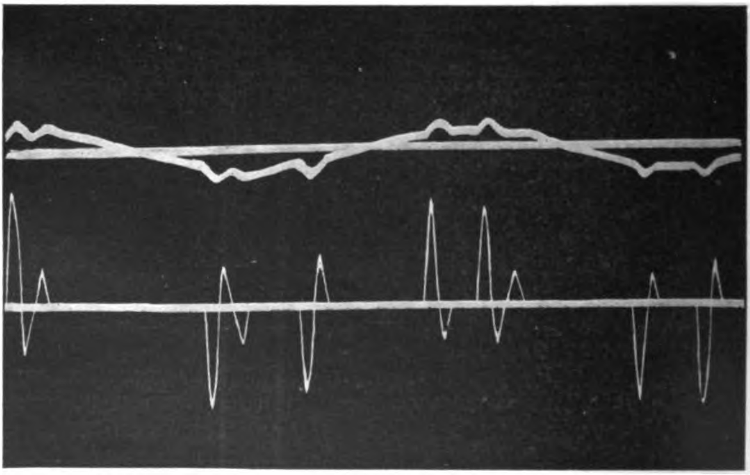


Fig. 3

The oscillogram in Fig. 2 shows the voltage E at the transformer terminals, and the current I_2 in the line and the transformer, without aluminum cell protection.

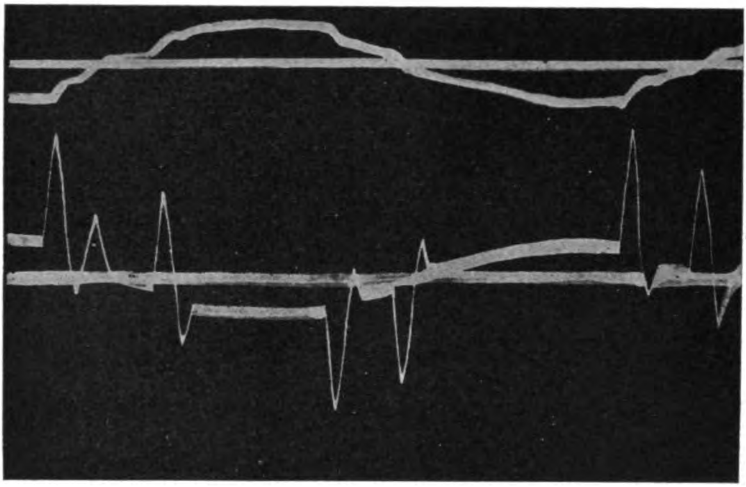


FIG. 4

The low sine-wave in the upper curve is the normal 60-cycle voltage of the transforner, and the oscillatory impulses carry the voltage up to ten or fifteen times the normal value. Of this excess voltage much is probably concentrated at the end-turns of the transformer. In the lower curve, no 60-cycle sine-wave appears, as the secondary $a\ b$ of the transformer was not loaded.

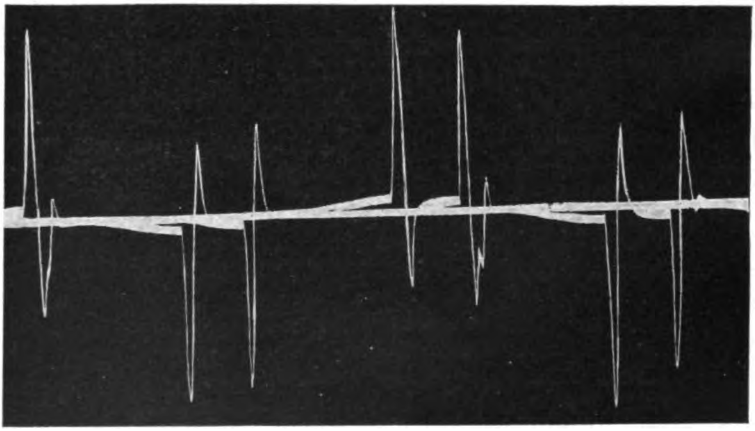


FIG. 5

It is interesting to note here and in the following voltage oscillograms the appearance of higher harmonics in the wave-shape of the oscillations. An aluminum cell was connected across the transformer terminals, at *a b* in Fig. 1. The oscillograms of voltage *E* and current *I*, under these conditions are given in Fig. 3.

The current impulse coming from the line *a b* appears unchanged, but the high voltage peaks of Fig. 2 have entirely disappeared, and only slight rounded kinks show where they would have occurred without the aluminum cell.

To see what becomes of the oscillating current *I*, oscillograms were taken of the current I_2 in the transformer and the current I_3 in the aluminum cell. These are shown in Fig. 4.

The entire current impulse passes through the aluminum cell, the lower curve in Fig. 4, while the transformer current shows only a very slight kink at these points, less even than the voltage curve in Fig. 3.

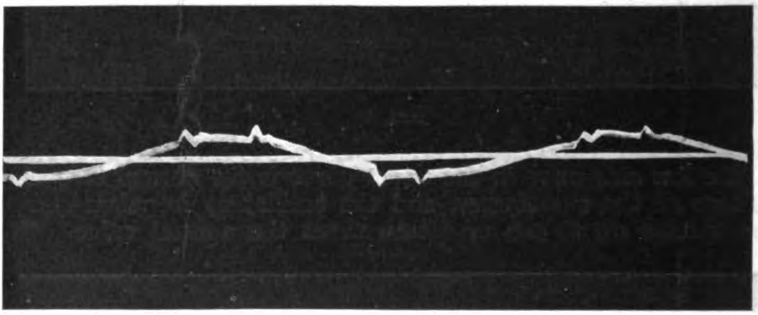


FIG. 6

Figs. 5 and 6 show oscillograms of the voltage *E* at the transformer, with and without the aluminum cell, the latter being shown on a larger scale. As will be seen, the enormous sharp voltage peaks entirely disappear owing to the presence of the aluminum cell. The latter thus protects the transformer without causing any disturbance in the system.

H. W. Fisher: Mr. Sprong has told me that he started these experiments with some misgiving. If he had obtained voltages approximating ten or fifteen times the normal voltage, as I believe Dr. Steinmetz predicted on some of the experiments on the Manhattan Railway cables, great damage might have been done to the system. We probably do not realize the risk taken in putting these surges and oscillations on the lines, and for a paper of this kind, giving the results of tests made for the purpose of observation to improve our systems and methods of operation, I think the Institute is especially indebted to the person and company who took that risk.

John B. Taylor: I think there is little question at to the effectiveness of the aluminum-cell arrester. It seems to be the closest we have come in electrical circuits to approximating the safety valve on the steam boiler. Doubtless while many improvements will be made in its form and the materials of which it is made, the idea seems to be distinctly the proper one for protecting electrical circuits from abnormal rises of potential.

I do not understand the basis on which is figured such a marked reduction in natural frequency of system, as the length of cable in circuit is increased, because I do not see readily what combination of cable and apparatus is taken to be oscillating. The natural frequency, of course, is determined by a combination of inductance and capacity, and it seems to me that the inductance would be more or less fixed by generators and transformers, while the capacity would increase as the number of miles of cable increased. This would tend to leave the inductance a constant figure with variable capacity, which would tend to increase the frequency rather than lower it as more cables are connected in.

Are not these men magnifying the dangers of operating an alternating-current system? Is an oscillogram of charging current with prominent thirteenth harmonic any evidence of narrow escape from a dangerous condition? The finest sine-wave found on any generator will pass to a condenser a current which is far from a sine-wave. If the thirteenth harmonic were a constant-potential affair; if the generators were constructed to give the thirteenth harmonic, and maintain it at constant potential irrespective of current drawn at that frequency, the matter might be serious, although resistance will always damp, and variable inductance of apparatus containing iron will always prevent, perfect resonance.

I have said before in discussing papers, that harmonics in alternating-current systems are interesting, but very seldom are they found to be the bugbear that some of us are inclined to think they are.

Ralph D. Mershon: Am I to understand that Fig. 23 is intended to show a voltage wave of the generator on open circuit? I am surprised to see such a ragged wave. I did not know that any modern generators had such a marked effect from the teeth.

E. E. F. Creighton: It is not a modern generator.

Ralph D. Mershon: That explains it. I should greatly appreciate it, and doubtless other members present would also, if one of the authors would give us some data relating to the latest form of the electrolytic condenser for this or other uses. How durable it is when continuously subjected to voltage? How durable it is if it is intermittently subjected to voltage of any sort? What are the details of construction so far as they are willing or able to give them, both from a mechanical and a chemical standpoint?

Charles P. Steinmetz: I believe I can answer Mr. Taylor's question, as to why the frequency decreases with increase of number of cables. The oscillating circuit is shown in Fig, 3, and consists of a system of from one to twelve feeders, each feeder with its potential regulator, and all connected in multiple through a single potential regulator to the ground; that is, the grounding arc, over which the oscillating current passes, contains in series first a single potential regulator, and then all the cables with their regulators. All these cables which their regulators in multiple would keep the same frequency, no matter how many cables, because the ratio of inductance and capacity remains the same, but as they are all in series with a constant inductance, the frequency increases with the decrease of number of cables, and the resultant frequency can be calculated from the number of cables, and the inductance and capacity, and checks well.

E. E. F. Creighton: Dr. Steinmetz has already answered the question relating to the variation in natural frequency. I might simply add that we gave no calculations at all on that subject. The results are all measurements. The matter that Mr. Taylor brings up, regarding the thirteenth harmonic disappearing, is worthy of still further comment. In Fig. 23 the oscillogram is shown first on open circuit, but the fact that a load is placed on that machine does not destroy the harmonic. There is always a possibility of getting the harmonic any time under the proper conditions, even though there be a great deal of power taken from the generator at the same time. The thirteenth harmonic may be brought out by the proper capacity and inductance relation, or by the proper length of arc connecting it to ground.

There have been a number of tests made of the effect of the length of arc on the frequency, and one laboratory experiment brought it out very clearly, without the aid of oscillograms. By placing an electrolytic condenser in series with the primary of the transformer, the amount of energy and voltage could be limited, Then, putting on the secondary side—the high-potential side—a spark-gap that could be varied, it was possible to open the spark-gap and get different musical notes at different lengths of arc, showing that the frequency—the artificial harmonic—actually does change with the length of gap.

In regard to the construction of the different aluminum protectors, there are three types at the present time, one that has been in use for some time, known as the gap-aluminum arrester consisting of nested plates. In that case there is always a gap in series, set at a voltage slightly above the line voltage, the minimum being, say, about 25 per cent above the line voltage. The length of time that any one of these arresters will operate depends entirely on the construction. The normal construction gives an operation of about 30 min. without any damage to the arrester. The lower voltage arresters, having a greater radiating surface, will operate for a long time without overheating.

A test was made on a 100,000-volt arrester, that being the maximum voltage in use, and the discharge was allowed to play for 40 minutes. The temperature rise at the top of the coil was about 18 deg. That type of arrester has been thoroughly tried out at the present time, and aside from slight changes, which will not affect the arrester in general, it is presumed at the present time that it is in a finished condition.

The second type of aluminum arrester is that used on direct current; that is, used without any series gap. Where direct currents are employed the loss of energy in the film is very slight, and consequently it becomes a very easy matter to connect the cells directly to the circuit without a series gap. In that case a single cell, operating on a potential of 300 volts, will have a loss of energy, internally, of very much less than one watt, the exact amount being 300 times 0.001, or about 0.3 watt for normal operation.

The other type of protector is illustrated in the paper, and consists of a number of cells connected in series and directly connected to the line, using alternating current. That corresponds to the direct-current arrester just described. In this case it is necessary to give a great deal more area of radiation in order to get rid of the extra amount of heat which is caused by the alternating current, the latter destroying and reforming the film every half cycle, and in that way giving a considerably greater loss of voltage as compared with the direct-current cell. It is also necessary in that case to place across each one of the cells a potential regulator, which is nothing more or less than an auto-transformer. The discharge rate of these cells at double voltage, is somewhere between 200 and 400 amperes, and can be measured by an ordinary ammeter, the cells being able to carry the current during that period. The discharge current at normal voltage is a fraction say about 0.2 of an ampere.

Ralph D. Mershon: What is the voltage to which each cell is continuously subjected ?

E. E. F. Creighton: 220 volts in the latter case.

Ralph D. Mershon: What would be the magnitude of the loss in a case like that?

E. E. F. Creighton: It would be a few watts per cell.

Ralph D. Mershon: Are the cells quite small?

E. E. F. Creighton: Yes; fairly small, about a quart size.

Ralph D. Mershon: What area of plate would that correspond to?

E. E. F. Creighton: That varies in the different cases where we made our tests. We have used large plates and small plates, and it all depends upon the general design. By giving more cooling area a larger plate may be used. Of course the idea is to use as small a plate as one consistently can and have the protection.

Ralph D. Mershon: Is there not some relation between the size of the plate and the amount of discharge the arrester will take care of?

E. E. F. Creighton: Yes; there is a direct proportion. For instance, the larger the plate area the more discharge is obtained at double potential, which really gives the capacity of the surge protector expressed in kilowatts, in the same way as with a transformer. The service the surge protector will be called upon to give is one of the objects we had in making these tests.

Ralph D. Mershon: What happens when the surge protector is too small?

E. E. F. Creighton: It takes energy from the surge proportional to the abnormal voltage and it must necessarily lower every surge that comes on the system.

Ralph D. Mershon: If your plate is not large enough, what results—does it blow the electrolyte out?

E. E. F. Creighton: We have not found anything of the kind so far. The cells will stand a great abnormal voltage, just how much cannot be stated simply—we have had three or four or five times normal voltage for a brief time on them without causing any trouble. It has to be brief in that case, because the size is small, and the current that flows, due to the abnormal voltage, is power current, and therefore an energy loss.

Ralph D. Mershon: I should think that if a heavy discharge took place there would be enough steam formed to make trouble.

E. E. F. Creighton: The one case given here, where a cell was places across a regulator and the regulator then grounded, gave a very large rush of current through the cell. The cells were exceedingly luminescent, and it was apparently a case of severe arc over the entire area of the plate, and still no change resulted from it. Of course, in that case the voltage was somewhat limited. Furthermore it was quite possible that the frequency it was very high, somewhere in the neighborhood of 20,000 cycles, being the natural frequency of the cable without the regulator in series.

Ralph D. Mershon: Is this regulator across each set of cells a transformer with the taps brought out?

E. E. F. Creighton: It is an auto-transformer.

Ralph D. Mershon: Will not the cells divide the voltage properly?

E. E. F. Creighton: They divide the voltage fairly well, but better results are obtained by using the transformer.

Ralph D. Mershon: Why will not they divide the voltages; because the capacities are not the same?

E. E. F. Creighton: Because slight differences between the cells and little impurities in the plate cause a difference in the capacity current, or energy current, and consequently a variation in voltage resulting from it.

Ralph D. Mershon: Things other than the density of the electrolyte, size of plate itself, etc.?

E. E. F. Creighton: Yes; each has an effect entirely aside from them.

Ralph D. Mershon: Will you explain the matter of destruction and re-formation of the film?

E. E. F. Creighton: The film seems to consist of two parts: there is a skeleton part that requires a long time in forming and seems to be very little affected. Then, apparently, inside of that skeleton, is formed a gas or a liquid of some kind that can be dissolved out. This is dissolved out in every case of every electrolyte that we know of at the present time.

Ralph D. Mershon: That is, if you let the cells stand?

E. E. F. Creighton: Yes, if the cells stand without any current. That same dissolution takes place if the current is reversed, or something similar to that dissolution takes place. That is what causes a loss of energy, we presume, in a cell when the alternating current passes through it; whereas the loss of energy is only a fraction of a watt on direct current, it is several watts on alternating current.

Ralph D. Mershon: On the alternating current, though, is there enough change to alter the color of the film?

E. E. F. Creighton: Yes; this skeletion, when the cells are first formed, has an iridescent color on the outside of the plates. After the cells have operated for a long timg, the skeleton becomes thicker, although the film, apparently, does not change; that is, the film thickness is of about the same capacity as before. As it ages it becomes frosty in appearance.

Ralph D. Mershon: What means do you have for cooling?

E. E. F. Creighton: That is obtained by immersion in oil.

Ralph D. Mershon: By the immersion of the cell itself?

E. E. F. Creighton: By the immersion of the cell itself, in case of the gap aluminum arresters, where a stack of cones is immersed in a tank of oil. In the case of the surge protector, which is the aluminum arrester without the gap, each separate cell is immersed in a horizontal tank or trough of oil.

Ralph D. Mershon: Can you get enough convection in the oil to keep it cool?

E. E. F. Creighton: Yes.

Ralph D. Mershon: In the case of the arrester with a gap in series, is the gap closed at intervals to keep the arrester in operative condition?

E. E. F. Creighton: The normal method is to have a switching arrangement. The gap itself is a switch which can be closed, but it seems that once a day is the best time to do it. It may stand for a long time, especially in cold weather, but charging it every day keeps down that first initial rush of current which must invariably take place in every aluminum cell. Each day that it stands the dissolution increases, and the initial current rush is greater; so if it stands for some time the initial current rush may easily be as great as 300 amperes. That will vary somewhat with the nature of the electrolyte.

Ralph D. Mershon: How many cycles does it take for the film to get back into proper condition?

E. E. F. Creighton: The oscillograms show that it requires just a few cycles for the film to re-form. It is only a momentary rush, which might be compared to the rush in the transformer when it is first thrown on the circuit, it unbalances magnetic conditions.

Ralph D. Mershon: Is that found in the case of a perfectly new cell, or in the case of a cell which has been formed once?

E. E. F. Creighton: In every case, where it has stood in the electrolyte.

Ralph D. Mershon: Whether is has had current or not?

E. E. F. Creighton: Whether it has had current or not, if it has stood any length of time.

Ralph D. Mershon: If you put the raw plates in the electrolyte?

E. E. F. Creighton: I misunderstood your question. It is usually impossible in that case to form the plates. They must go through a preliminary process before that is possible.

Ralph D. Mershon: As to the forming process, and the electrolyte, is that a secret at the present time?

E. E. F. Creighton: Yes; at the present time; these things are still in the patent department.

Charles P. Steinmetz: I think I can answer the remaining question, as to the destruction and re-formation of the film. The oscillograms taken of the voltage and current of the aluminum cell in good operating condition show that at the reversal of electromotive force a slight re-forming of the film is necessary.

An extensive investigation of the operation of the aluminum cell, under normal and under abnormal conditions, on alternating voltages and oscillating discharges, has been made in my laboratory by my assistant Mr. J. L. R. Hayden, by means of the oscillograph. As the interest shown in the subject by the discussion seems to warrant it, we shall present the results in a paper before the Institute at an early date.

DISCUSSION ON "SOME CONSIDERATIONS IN DESIGNING HEAVY CAPACITY FUSES." FRONTENAC, N. Y., JUNE 30, 1909

(Subject to final revision for the Transactions.)

Louis W. Downes: In making these investigations, the conditions on heavy overload and on short-circuits were principally considered. The analyses of the curves show to what a remarkably uniform degree they sustain the theory of proper fuse design, as I believe it is given in the paper. I would ask your special attention to the summary of the curves given in Fig. 8, and particularly to a comparison of tests 9 and 10, Figs. 12 and 13.

C. Francis Harding: In this and other papers presented before this convention, it is interesting to note the use of the oscillograph in studying electric phenomena under widely varying conditions. Several years ago when I made tests of enclosed fuses, the oscillograph had not been introduced for this purpose. It was attempted to determine the energy taken by the fuse under full-load, overload, and short-circuit conditions by measuring the resistance of the link and calculating the energy as I^2R loss. It was thought that a considerable discrepancy might exist in this method because the resistance was taken across the link alone, while there might also be a fairly high resistance in the joint between the link and the blade. There was, of course, resistance in the blade itself which caused heating. It was difficult, therefore, to determine just the amount of energy used in the fuse link itself—energy which must be carried by conduction to the tube and later radiated to the air.

Mr. Downes states that he has used and still uses that method in addition to the oscillograph method, and has calculated the energy taken by the fuse from the measurements of resistance as well as from the product of volts and amperes taken from the oscillograph. However, he has not compared these two methods of determining the energy. It would be interesting to determine how much of this heating comes from the soldered joint, how much from portions of the blades and how much from the link. As I understand it, the oscillograph product of volts by amperes would give the total energy expended in the fuse.

It is stated in the paper that the advantage of the multiple link over the single link is principally due to the shortening of the path through which the heated gases must be conducted to the tube, and also to the increase of surface area of the link. The fuses are identical as far as the blades are concerned, but I do not understand that the supports of the links are the same. I wish to ask how much of this difference between the action of the multiple link and that of the single link may be due to the conduction of heat away from the link, due to the difference in the support, the multiple link having a much heavier support than the single link?

I would also like to know what effect a change in filling would have with the single link. I take it that the filling is the same in all cases. With the single link a larger amount of gas is generated in a small space than with the multiple link, and it would seem that if the voids in the filling were greater with the single link than with the multiple link there might be a freer path for the gases to reach the blow-holes, and possibly better operation of the single link in that case.

In the last paragraph of the paper the question of moisture in the filling is taken up, and it is also stated that the fuses were tested directly on short-circuit, without apparently anything being said about full-load or part-load operation. It seems to me that this condition is a bit different from that to which the fuses would be subjected in practice. Ordinarily the short-circuiting occurs with the circuit previously closed; that is, the fuses are under heavy load, three-quarters, or perhaps full load when the short-circuiting takes place. If the moisture—3 to 5 per cent in these fuses—be dissipated by the heat before this short-circuiting takes place, and held somewhere in the fuse ready to produce energy in the form of steam when the short-circuit occurs, this condition is different from that in the tests. As is well known, most of the fillers used in fuses are more or less hydroscopic, and the amount of the moisture in the filler will probably vary with the weather conditions and with the particular atmosphere in which the fuses are operated.

J. C. Lincoln: I wish to enquire as to the accuracy of these enclosed fuses. For instance, working at nearly full load, are the fuses accurate within 10 per cent or 20 per cent, or about what is the limit of accuracy which they may be expected to show? Secondly, is the fuse material itself of such a nature that when the fuse blows the gases will have the effect of blowing out the arc? I understand that some of the metals, in which zinc is one of the components, have this property to some extent. Is anything of this nature used in the fuse link itself?

W. S. Andrews: The paper shows the wonderful development of the art since the time, now nearly thirty years ago, when by mere chance I was called upon by Mr. Edison to make the first fusible links that were ever used for the protection of incandescent lamp circuits. Most of the fuses used in those early days were open, but a patent was allowed to Mr. Edison in 1880 for an enclosed fuse. It was customary to clamp the bare fuse wire under a screw-head, and this naturally made poor contact. To correct this, the late Luther Stieringer invented what he termed a "hard end fuse," which, as is well known, consisted of a fuse strip with copper ends. This improvement constituted the first important step toward the production of a reliable fuse link. A patent on this improved safety fuse was allowed to Mr. Stieringer in 1886.

A. E. Kennelly: The oscillograms in the paper are of great interest and value because they indicate the electrical actions that may occur when a large storage-battery is suddenly placed on heavy short-circuit close to the switchboard, and also how severe are the duties of an enclosed fuse in such cases.

It will be seen that the current starts to increase at the rate of some 2,000,000 amperes per second. If the fuse does not suppress the enclosed arc in the first 0.01 sec. or so, the energy liberated within the fuse itself will be enormous.

Even when the fuse performs its functions promptly and satisfactorily, the quantity of energy liberated within it is about the same as in the cartridge of an ordinary shot-gun when fired.

Moreover, it is desirable that the rate of throttling of the current should be fairly uniform, otherwise there will be a considerable rise of voltage induced in the circuit by $L \frac{dI}{dt}$.

Louis W. Downes: In replying to Mr. Harding's questions in regard to the variation in construction between the different fuses used in these tests, I will say that he is mistaken in his inference that there was a difference in the construction between the multiple-link and the single-link fuses tested. They were all identically the same, particularly the terminal wires; these were of the same length and of the same cross-section. The only difference in construction is that shown in the method of supporting the fusible portion of the link. That is shown in Chart 3 and Chart 4. In the five-wire multiple link there is a small star-shaped stamping of hard metal through the center of which the terminal wire, shown by the circle, is carried and to which it is soldered, the terminal wire being identically the same in all fuses.

The spacing in the filling, within certain limitations, has little to do with the case beyond a certain point; namely, it permits the escape of the gases, but if the spacings are too large, so that there is too great a flow of gas through any one section, then trouble will be experienced.

I believe the oscillograph tests clearly sustain the theory that the chief function of the filling in the enclosed fuses is to act in the capacity of a condenser; in other words, the volatilized metal of the fuse-link possesses a relatively high conductivity while hot. Below a certain temperature that conductivity ceases to exist and the condensed gas actually becomes an insulator, or at least possesses high insulating properties. Consequently, if a very coarse filling were used, having of necessity wide spaces among the particles, the volume of gas rushing through these spaces at one or more points might affect the cooling action of the filling to such an extent that the temperature of the gases would not be brought to a sufficiently low point to destroy their electrical conductivity; hence the arc would be maintained by the passage of the current through such a vapor path. It is desirable, therefore, to have the filling broken up into as fine particles as possible so as to present the greatest possible condensing surface to the hot gas, bearing in mind at the same time that the degree of fineness must not be such as to interfere with the ready passage of the gases through the mass of the filling. From this it will be seen that it is desirable to avoid too large spaces among the particles of the filling, and so to arrange the elements of the link that every particle of filling can be brought into action in the shortest possible time. In that way alone can we prevent the maintenance of an arc within the fuse. If the arc is not interrupted, explosions or disruptions of the casing will soon result.

Mr. Harding further referred to the presence of moisture in the filling, and asked if it were not a fact that in fuses under load the moisture would be largely driven out by the high temperature of the fuse-link within the casing. We have found bv rather an extensive investigation that it is extremely difficult to drive out all the moisture contained in the average porous filling. I wish to say, incidentally, that every enclosed-fuse manufacturer to-day is using for filling purposes practically the same material; namely, the different salts of calcium—calcium carbonate and calcium sulphate particularly.

We find that a filling as it comes from the mixers, ordinarily will contain from 16 to 18 per cent of moisture, and it is necessary to raise it to a temperature of between 600 and 700 deg. fahr. to drive this moisture off to any extent. After the moisture is down to about 4 or 5 per cent it will remain practically a constant factor and does not seem to be affected materially by atmospheric conditions, as we have exposed filling to the atmosphere in very foggy weather and have found no appreciable increase in the percentage of moisture, provided it has first been brought down to 5 per cent.

I do not think that Mr. Harding is correct in stating that an enclosed fuse at full load would have all the moisture driven out, because there is only a very small part of the fuse which approaches the high temperature necessary to drive the moisture off; that is, the part immediately in contact with the metal of the link, which if of zinc would run approximately between 500 and 600 deg. The exterior casing, however, runs at a very much lower temperature, about 160 deg. to 165 deg. being approximately the limit. This temperature limit is fixed by the fact that continued operation of the fuse at 175 to 180 deg. will rapidly destroy the fibre tubing, which will then become very brittle and would be likely to explode should the fuse be subjected to a heavy short-circuit.

Mr. Harding also asked where these tests were made—more particularly the short-circuiting—and if they actually represented a practically operative condition. As a matter of fact, the investigations were made with the idea of determining accurately the best method of avoiding the most serious difficulty of enclosed fuses; that is, explosion of the casing. Manufacturers had been troubled from time to time by the terrific explosions of the enclosed fuses, which were dangerous not only to property but to life if a man happened to be near the fuse when it exploded. Those explosions occured in the commercial operation of the fuse, so I do not feel it can be said that we have imposed impossible conditions upon the fuse in these tests.

A large amount of energy is available at the switchboard of stations all over the country, and a fuse is frequently called upon to withstand direct short-circuits under the most severe conditions. As an illustration, in New York City the fuses on the elevated railway and on the subway, with the enormous generating stations back of them, are carried on the truck and are there relied upon to sustain practically direct short-circuits between the third rail and the structure. A fuse that will not withstand that test is not only of no value, but is also a considerable menace to the company; for if one of them should explode as a train is drawing into a station, the result would be disastrous to the company financially from resultant damage suits.

In regard to Mr. Lincoln's inquiry concerning the accuracy of of the fuse and the nature of the fuse metal, I would say that the accuracy of the fuse of course depends very largely upon the care with which it is designed, but it is not difficult to make a fuse which is within 10 per cent of its ratings. The great difficulty in the enclosed fuse is the difference in the overload blowing time when a fuse is first put into the circuit and after it has been in the circuit for some time, due to the fact that the heat conductivity of the porous material which is immediately in contact with the metal of the link of course rapidly decreases as the temperature rises. That to a certain extent does affect the accuracy of the fuse, but not to an extent which renders its use impracticable. There are several methods of overcoming this defect, the most common being the notching of the link to bring about a high current density at the center; and the other, the use of the air drum. By confining a small body of air immediately about the central part of the link, the heat is less rapidly absorbed by the filling at that point. That fuse possesses an astonishingly high degree of accuracy whether cool or hot. Its characteristic curve will be found to run uniform and the blowing time at any given overload is constant.

Mr. Lincoln's other inquiry as to whether any metal was employed which possesses a tendency to blow out the arc, I have already referred to by stating that the filling was what destroyed the arc by condensing the conducting medium; namely, the metallic vapor at the time of the operation of the fuse. As far as I know, there is not any practical difference in the arcing effect of any of the softer metals, such as zinc, aluminum, lead, tin alloys, lead-bismuth alloys, or in combinations of these—all of which I have tried very extensively and in a great many different mixtures. The harder metals, copper and silver, owing to their higher boiling point, are not well adapted for use in fuses, particularly enclosed fuses. The higher melting point affects them and the conversion of the metal into its vapor is accompanied by a more explosive action. I doubt very much if any effective results would be produced by what Mr. Linclon referred to; that is, the so-called tendency of the gases of some of the metals to extinguish an arc.

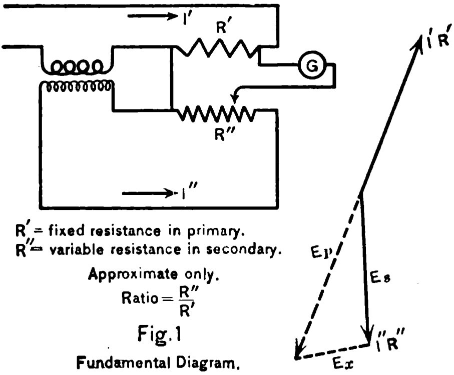
DISCUSSION ON "ELECTRICAL MEASUREMENTS ON CIRCUITS REQUIRING CURRENT AND POTENTIAL TRANSFORMERS." FRONTENAC, N. Y., JUNE 30, 1909

(Subject to final revision for the Transactions)

C. H. Sharp: This important question of the measurement of ratio and phase-angle of transformers is beginning to receive the attention it deserves. I should like to call attention to similar work done at the Electrical Testing Laboratories under my direction by Wm. W. Crawford.

By the two-ammeter method of measuring the ratio of current transformers, it is possible to get quite accurate results, but their accuracy is limited by the steadiness of the available alternating-current supply. It is also desirable that the two instruments should have as nearly as possible the same natural frequency of oscillation.

Being dissatisfied with the results obtained by the two-ammeter method, we sought a method which would be free from its disadvantages, and two years ago worked out the two-shunt method outlined by Mr. Robinson. This is essentially a bridge or zero method in which the fluctuations of the supply do not go into the result directly, and which has also the great advantage of giving the result in terms of the ratio of two resistances. We have developed also the shortcomings of this method, which are described below, and have devised means whereby they might be overcome and also a scheme for measuring the phase-angle of the transformer at the same time that its ratio of transformation is obtained.



R' = fixed resistance in primary.
R'' = variable resistance in secondary.
Approximate only.
Ratio $= \frac{R''}{R'}$

Fig. 1

Fundamental Diagram.

The simple connection shown in Fig. 4 of Mr. Robinson's paper does not give a wholly exact value for the ratio of the transformers, for the reason that the primary and secondary currents are not in phase with each other and their phase-angle increases with decreased load. Referring to Fig. 1, we have e_p the fall of potential on the primary shunt, e_s that on the secondary shunt, and e_x the reactive potential difference which is present even when $e_p = e_s$ numerically. Now, if the rotating commutator is adjusted so that its axis of commutation bisects the angle between e_p and e_s, the galvanometer measures the difference between the projection of e_p on the axis of commutation, and of e_s on the same axis. When the deflection of the galvanometer is reduced to zero by adjusting the secondary shunt, the ratio of shunt resistances gives very accurately the ratio of the transformer. The difficulty is to set the axis of commutation to approximately the right position. If this axis of commutation falls some distance outside the angle made by e_p and e_s, the ratio measured will be incorrect.

To obviate this difficulty, the reactive potential difference e_x must be nullified. The first method used for this purpose is illustrated in Fig. 2. In this method a fixed non-inductive resistance R'' is introduced into the secondary circuit, and this is shunted by a potentiometer arrangement R_s of 100 ohms, in series with which is a variable standard of self-induction L by means of which the current through R_s may be brought into phase with that through R'.

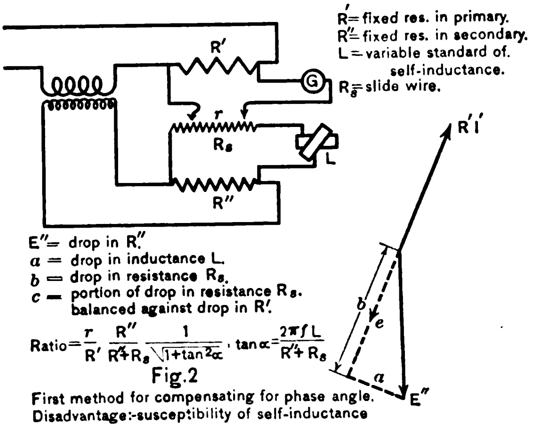

R′= fixed res. in primary.
R″= fixed res. in secondary.
L = variable standard of. self-inductance.
R_s= slide wire.
R′
G
r
R_s
L
R″
R′I′
E″= drop in R″.
a = drop in inductance L.
b = drop in resistance R_s.
c — portion of drop in resistance R_s. balanced against drop in R′.
$\text{Ratio} = \frac{r}{R'}, \frac{R''}{R''+R_s} \frac{1}{\sqrt{1+\tan^2\alpha}}, \tan\alpha = \frac{2\pi f L}{R''+R_s}$
b
e
a
E″

Fig.2

First method for compensating for phase angle. Disadvantage:-susceptibility of self-inductance to stray field effects.

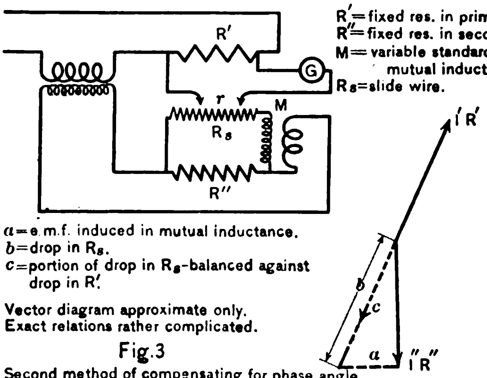
The procedure then is as follows: the axis of commutation is brought as nearly as possible into the general direction of the vectors of the fall of potential of primary and secondary shunts, by noticing the position of the commutator which gives the maximum sensibility to the arrangement; that is, the position in which a given change in the secondary shunt throws the apparatus farthest out of balance. Having determined this position, and having adjusted R_s so that the galvanometer deflection is zero, the line of commutation is rotated through an angle of 90 deg. At this point the sensitiveness of the arrangement in measuring the inductive difference e_x is the maximum, and the deflection here observed is brought to zero by adjusting the value of the self-induction L. This operates to bring the potential differences on the shunts substantially into phase with each other.

When this has been accomplished, the brush holder is rotated back into its original position and the adjustment of R_s is again made. The second value of R_s so found must be almost exactly correct since it is made when e_p and e_s are in phase with each other, and consequently the ratio of their projections upon any line gives the true ratio of the potential differences. The ratio of the transformer is then given by the expression:

$$\text{Ratio of transformation} = \frac{r}{R'} \quad \frac{R''}{R''+R_s} \quad \frac{1}{\sqrt{1+\tan^2 \alpha}}$$

where α, the phase-angle of the transformer is given by the relation,

$$\tan \alpha = \frac{2 \pi f L}{R''+R_s}\,.$$



R' = fixed res. in primary.
R'' = fixed res. in secondary.
M = variable standard of mutual inductance.
Rs = slide wire.

a = e.m.f. induced in mutual inductance.
b = drop in Rs.
c = portion of drop in Rs-balanced against drop in R'.

Vector diagram approximate only.
Exact relations rather complicated.

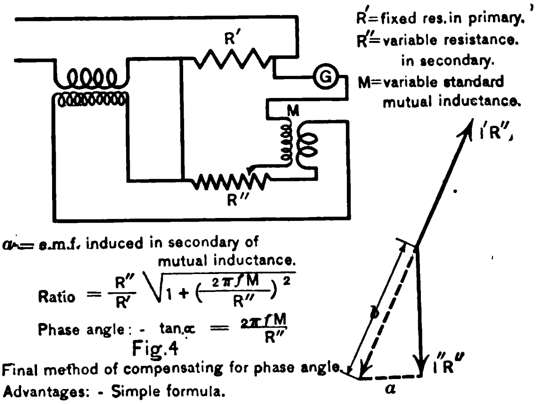
Fig. 3

Second method of compensating for phase angle.
Disadvantage:- complicated formula.

The principal disadvantage of this method is that the ordinary Ayrton-Perry form of standard of self-induction is such that it is subject to influence by stray alternating fields, and a very feeble stray field would in the case of these measurements be sufficient to destroy the accuracy of the measurements. It is evident that in the foregoing work, not only has the ratio of the transformer been determined, but at the same time the phase-angle between primary and secondary currents has been measured.

Following this, a second method, shown in Fig. 3, was developed in which a variable standard mutual-induction was substituted for the variable standard of self-induction, and since a standard of mutual-induction can be made astatic so as not to be influenced by stray fields, this difficulty of the first method was overcome. The relations involved in applying this second method are rather complicated, and as a result the method has been abandoned for one illustrated in Fig. 4, in which the arrangement of circuits was suggested by Mr. F. K. Vreeland. As will be seen, the primary of the mutual-inductance is in series with the secondary of the transformer, while the secondary of this mutual-inductance is connected in series with the galvanometer. The operations are exactly as described in the first method but the formula is even more simple than in that method, while the trouble from stray field is avoided by using an astatic mutual-inductance.

The methods here given have the advantage over Mr. Robinson's method of not requiring two wattmeters which are accurate on low power-factors, together with a voltmeter and ammeter, three observers, and a steady current. By this method not only is the true ratio of the transformer obtained as a ratio of resistances, but the phase-angle is measured by actually nullifying the reactive potential difference which corresponds to it.



R' = fixed res. in primary.
R'' = variable resistance. in secondary.
M = variable standard mutual inductance.

a = e.m.f. induced in secondary of mutual inductance.

$$\text{Ratio} = \frac{R''}{R'}\sqrt{1+\left(\frac{2\pi f M}{R''}\right)^2}$$

$$\text{Phase angle:} - \tan\alpha = \frac{2\pi f M}{R''}$$

Fig.4

Final method of compensating for phase angle.
Advantages: - Simple formula.
Less susceptibility to stray fields.
Greater sensitiveness.

With the exception of an ammeter to show approximately what the load is, no direct-reading instruments are required.

Moreover, the arrangement is independent of sensitive suspended instruments. It is quite feasible to use a resistance of very small fall of potential for the primary and secondary shunts and still have sensitiveness enough even when a pivoted direct-current galvanometer is used. On account of the character of the apparatus employed, it is possible by one of these methods to measure the ratio of a transformer installed on a switchboard and to do it with a high degree of accuracy. This at once extends the range of possibilities of this sort of testing beyond the walls of the laboratory—a very important consideration in many instances.

We have found that the rectifying commutator in the form in which Mr. Robinson describes it is not a success. As soon as the current becomes very small the contact resistance of brush with commutator is very uncertain, sometimes reaching a high value. We have obviated this difficulty by substituting a vibrating rectifying device operated by a cam on the shaft of the motor. Straight pressure contact instead of rubbing contact is thereby obtained, and operates satisfactorily. The primary non-inductive shunts for this sort of work present very serious problems of construction as soon as heavy currents have to be dealt with, and they must be arranged to be cooled by some liquid.

A similar method can be used for the measurement of the ratio of potential transformers. As a current detector an alternating-current—direct-current voltmeter can be used, provided its connections are changed so that its field coils can be separately excited. For most purposes the sensitiveness of such an instrument is sufficient. The methods and apparatus for carrying them out as described in the foregoing have been developed in the Electrical Testing Laboratories quite independently of any similar work done elsewhere.

M. G. Lloyd: Mr. Robinson's table and diagrams will no doubt be useful as showing the general way in which those quantities change with the conditions of load.

I think it may be of interest to speak of some methods that have been developed at the Bureau of Standards and are now being used in this kind of work. Referring first to the current transformer and the diagrams in Figs. 2 and 3: we tried out the first method and found it objectionable, at least not quite as serviceable as the method indicated in Fig. 4, and similar to the one described by Dr. Sharp, in which only two shunts are necessary in the circuit of the transformer. In addition to the points raised by Dr. Sharp, one other is that while there is no trouble in getting accurate measurements with the arrangements shown in Fig. 2, since a dynamometer must be in the secondary circuit, it limits the load conditions which must be used; that is, the resistance and reactance cannot be cut down below the values necessary for the watt-dynamometer itself. Consequently, the secondary circuit cannot be made as small as it might be in practice, and therefore as small as it would be desirable to have the conditions in calibrating.

The alternative diagram in the lower left-hand corner of Fig. 4, is a method that we have found of more service. At the terminals 2, we connected one coil of the dynamometer; the other coil had current supplied to it in phase with the primary of the transformer. The result is that the potentials across the two resistances, R_p and R_s are opposite and not exactly in phase, their resultant being a small voltage in quadrature, and the dynamometer is made to read zero. In the case of any good transformer the ratio of resistances gives the ratio of the currents since the cosine of the small angle is a negligible factor.

We have found it simpler to obtain the phase-angle measurement almost simultaneously by using a somewhat different scheme. Instead of using a three-phase supply we have tried using a two-phase source of supply, and we have found that preferable. Using a two-phase supply we have a second dynamometer whose field is supplied with current in quadrature; we then apply the same electromotive force, which represents the difference in the drop in the two shunts, R_p and R_s, to the other coil of the dynamometer having its field in quadrature. The deflection, then, measures a small quantity which, in ratio to the primary potential drop, gives the phase-angle of the transformer; so that by a simple throwing of the switch the second measurement is obtained.

The method with the mutual inductance mentioned by Dr. Sharp I believe is the same as that used at the National Physical Laboratory, in England, and described in their last annual report.

In regard to potential transformers, our method is very similar to that used by Mr. Robinson; that is, we balance a fractional part of the potential of the primary against the potential of the secondary. I need not speak of that in detail; suffice it to say that here again in obtaining the phase-angle we use the quadrature current as the auxiliary instead of the phase-shifting transformer, with the result that by simply throwing the same difference of potential on the second dynamometer, that quantity is measured directly and gives the phase-angle. These methods which we have finally found the most preferable were given several months ago in a paper read before another society.*

As Mr. Robinson has pointed out, the transformer is an instrument of precision when used under proper conditions. There is one way, however, in which an error may be introduced even when the transformer has been calibrated and when it is not subject to such errors as aging. That is due to the fact that iron requires a different magnetizing current in some cases from what it does in others. Such a case can be brought about by magnetizing highly in one direction and then subsequently breaking the magnetizing current. It will be then in a condition that is not neutral. If that operation is performed with the current transformer, and its ratio then measured, it will be found that the ratio will not be of the same value as when the iron is in a neutral condition.† That does not apply to a potential transformer, because there the magnetizing current comes in only as a second-order effect. In the current transformer, where the ratio is thrown off from the nominal value entirely by the exciting current, this effect comes in very strongly and may produce an appreciable error.

Hence when calibrating the current transformer and using it afterwards, one should be sure that a definite condition of the iron exists. That can be arranged by putting the core through a demagnetizing process before using it. Such an abnormal condition may easily result, because if the secondary happens to be open-circuited we have the condition spoken of. The magnetism of the core jumps to a high point and if the flux is suddenly cut down by closing the secondary, it is brought down without the demagnetizing process.

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* Agnew and Fitch, *Phys. Rev.* 28, p. 473; June, 1909.

† Attention was first called to this by Agnew and Fitch loc. cit.

In regard to which angle should be called positive and which negative, I wish to take issue with Mr. Robinson. The point mentioned earlier, depending upon whether we shall call a lagging angle positive or negative, I will not go into because that is a point which depends largely upon the way in which one has been trained. But coming to the specific case of designating these angles, it seems to me that the method used in this paper is inconsistent and undesirable. It will be noticed in the case of the current transformer that when the secondary leads, the angle is called positive, and in the case of the potential transformer it is called negative. There is an inconsistency between the two cases. The reason for doing this is to make it possible to take the sum of the two angles and determine the apparent power-factor. It seems to me that is confusing. Anyone understands that if the current and the potential are thrown off simultaneously in the same direction; that is, if each one is caused to lag by the same number of degrees, the reading of the wattmeter will not be altered. The first thing that naturally occurs to one is that the difference of the two phase-angles must be taken. So it would be more logical and less confusing to call the phase-angle positive in one definite direction, preferably when the secondary leads.

In the formula on the fourth page, I would suggest that having indicated which angles are positive and which negative, it would be better to omit the combined sign plus and minus and let it stand as plus.

In an early part of the paper under the things to be investigated, Mr. Robinson has mentioned the effect of wave-form. I think he takes up all the other points, but he says nothing further about this. Over a year ago I published an article* giving some experiments on that point. The results showed that with any distortion that would be likely to be present on an ordinary circuit, the ratio is not affected. There is a small effect with very large distortion. In a book by Arnold,† this section of which was written by LaCour, there is a theoretical discussion on this subject, based on the assumption that harmonics can affect the result only by their value and regardless of their phase. In other words, if the same harmonics are in such phase as to produce a flat wave and a peak wave, the result should be the same. This is not in agreement with the experimental facts.

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* *Electrical World* 52, p. 845, 1908. *Bull. Bur. Stds.* 6, No. 1, 1909.

† Wechselstromtechnik, Vol. 1, p. 254.

L. W. Chubb: I would like to ask if the transformers giving the curves shown in Figs. 7 and 8 were of special design for the test, or whether they were commercial transformers, and what were the load conditions 1, 2, 3, 4, and 5?

I would also like to ask Dr. Sharp if the extra circuit containing the resistance and inductance as shown in his diagram would take enough current to prohibit getting any desired conditions of instrument load during a test?

Albert F. Ganz: I wish to ask Mr. Robinson whether he has any method to suggest for measuring the phase-angle α in the wattmeter itself, also whether in a properly designed transformer, β is not always positive and γ negative? Is there anything about the tests that will enable one to tell whether these angles are positive or negative?

C. H. Sharp: Answering Mr. Chubb's question: in this method of testing current transformers the high relative sensibility of direct-current galvanometers can be utilized. Consequently it is not necessary that the fall of potential in these shunts should be large. As a practical matter we work with one-quarter of an ohm in the secondary circuit of the transformer, but we could just as well use two-tenths or one-tenth. The inductance, is entirely negligible.

L. T. Robinson: In reply to Dr. Sharp, I would say that it is not necessary to take into account the small error due to the fact that the primary and secondary currents are not exactly in phase. I think that the somewhat elaborate arrangements which he has shown are an entirely unnecessary refinement. By reference to a table of cosines it will be seen that if the transformer is reasonably good; that is, if the angles are nearly as they should be, it will be entirely beyond the accuracy wanted in a commercial test. If the angle β is as much as 2 deg. the necessary correction ($\sec \beta - 1$) amounts to only about 0.05 per cent. If desired, correction can easily be made for this small angle, but if a transformer were brought to me for test, and I had to take this correction into account, I would not make a complete test. The transformer would evidently not be a good one.

I think that the method suggested for measuring the phase-angle is very ingenious. I have not had the time to try it but my opinion is that it would not allow a determination to be made with the same degree of precision that could be obtained by using the method given in the paper.

The question was raised as to the number of observers and the time required to complete the work. I would say frankly that I expected better results with the resistance methods that have been described, and the only reason I can give for not having adopted long ago for commercial work what will no doubt prove to be the final method is, that where one has so much to do it is difficult to always bring into daily use methods which promise to be better. I am quite willing to say, however, that from my point of view the length of time for these tests is quite satisfactory.

The commutator I myself do not like. We did try it and it will work, but I think I would prefer some other method.

Dr. Lloyd referred to Figs. 2 and 4. I prefer Fig. 4 unless some arrangement like that shown in Fig. 6 can be used. I believe this will be the ultimate outcome.

It is true that the secondary load conditions are limited by the dynamometers. From my own point of view this is no objection, because we can go to the limits of the smallest connected load that it would ever be necessary to use, and there is no use in going further. For precision work we would not use a transformer with less on it than one portable ammeter and one portable wattmeter, and the combined load of these two is just about equal to what we can easily get by the methods we have used.

As to the effect of the altered magnetizing current due to the previous state of the core affecting the ratio, I would say that this fact has been appreciated for some time. I thought it was so well known that I did not need to refer to it. All users of current transformers have for some time been cautioned against leaving the secondary circuit open.

M. G. Lloyd: The same effect is brought about if the dynamometer is calibrated with the secondary or primary in circuit with direct current.

L. T. Robinson: I know that, but we do not do it.

As to the angles and sines, I appreciate this fact, that it may not be logical and I do not offer it as such; but after one has carefully selected the best method and no one else is doing the same thing at that time, the only way is to proceed and afterward tell how it was done and what one's opinion of it is. I am perfectly willing to make a change if we can come to any satisfactory understanding about what it is best to do.

In reply to Mr. Chubb's question as to the loads used: I described their properties though perhaps not in sufficient detail. The loads are given in electrical terms and below is given a brief description of the actual loads used.

The tests of transformers were all made on commercial specimens. Professor Ganz asked how to determine the angle α. I would say that one cannot tell everything in a single paper. I shall be glad to tell him privately what we do.

J. Dalemont (by letter): I wish to call attention to the influence of the core-loss and magnetic leakage upon current transformers. I have recently made some measurements on two current transformers having iron cores of the same cross-section and nearly the same length, but of different form: one as in Fig. 1, the other as indicated in Fig. 2.

On one of the legs of the prismatic core, the following sets of coils were mounted in succession:

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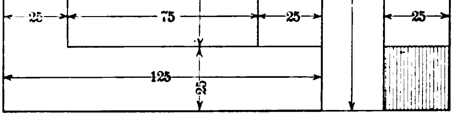


FIG. 1

almost sine shape and a frequency of 36 cycles. On the torus core, a secondary winding of 460 turns was wound uniformly. The primary wire carrying the current was placed in the direction of the axis of the torus, perpendicular to the plane of the

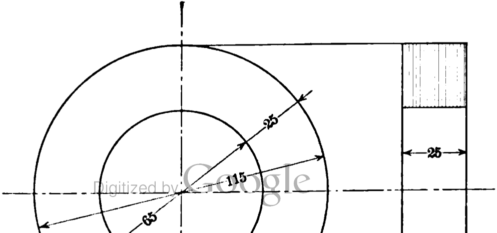


TABLE I

Ratio $\frac{5}{460}$		Ratio $\frac{41}{460}$		Ratio $\frac{1}{460}$	
Core 1		Core 1		Core 2	
I_1 ampere	I_2 ampere	I_1 ampere	I_2 ampere	I_1 ampere	I_2 ampere
93	1.09	15.5	1.23	567	1.15
116	1.37	19.8	1.58	755	1.58
135.2	1.61	23.4	1.89	936	2
150	1.79	27.7	2.23	1021	2.18
170	2.03	32.3	2.62	1098	2.32
184	2.19	35.8	2.91	1175	2.52
205	2.45	39.2	3.17	1265	2.68
233.3	2.77			1355	2.87
263	3.13			1495	3.17
275	3.25			1670	3.54
299	3.53			1772	3.77

TABLE II

Curve 1		Curve 2		Curve 3	
$n_2 I_2$	$\frac{n_1 I_1}{n_2 I_2} - 1$	$n_2 I_2$	$\frac{n_1 I_1}{n_2 I_2} - 1$	$n_2 I_2$	$\frac{n_1 I_1}{n_2 I_2} - 1$
502	−.073	565	.122	529	.048
632	−.082	727	.115	727	.036
742	−.088	870	.102	920	.020
825	−.092	1025	.098	1000	.024
936	−.093	1205	.100	1068	.032
1008	−.088	1339	.095	1160	.030
1130	−.092	1458	.095	1232	.028
1275	−.087			1320	.026
1440	−.086			1958	.025
1498	−.082			1628	.025
1625	−.080			1732	.022

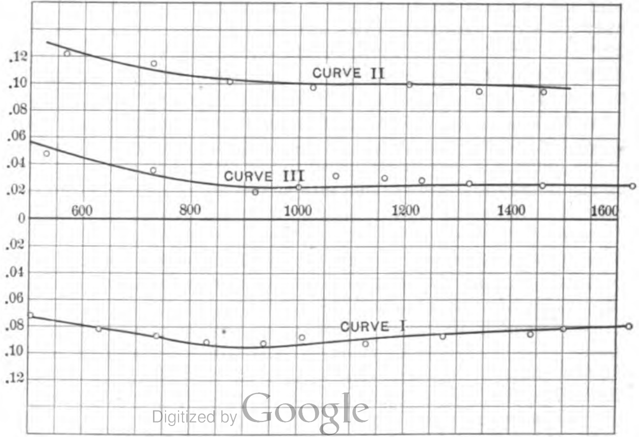
15 3	1 23	[illegible]	[illegible]
19 [illegible]	1 58	755	[illegible]
[illegible] 4	1 89	936	[illegible]
[illegible] 7	[illegible] 25	[illegible]	[illegible]
[illegible] 3	2 62	[illegible]	[illegible]
[illegible]	2 91	1175	[illegible]
39 2	3 17	1265	[illegible]
		1355	[illegible]
		1495	[illegible]
		1670	[illegible]
		1772	[illegible]

TABLE II

Curve 2		Curve	
[illegible]	[illegible]	[illegible]	[illegible]

circuit.

It will be seen that this ratio is equal to 1 when the losses are negligible.



DISCUSSION ON "THE TRAINING OF NON-TECHNICAL MEN" AND "THE VALUE OF CLASSICS IN ENGINEERING EDUCATION." FRONTENAC, N. Y., JULY 1, 1909.

(Subject to final revision for the Transactions)

C. P. Steinmetz: In the preceding paper I desire to make a strong plea for the reestablishment of the classics as one of the most important and valuable educational factors necessary to give that intellectual development and broadening of the mind which produces not merely intellectual machines, but citizens of the Republic capable of taking their proper place in the industrial and social life of the nation. From the standpoint of educational value I consider the classics superior to any modern language. I do not mean to say that modern languages should not be learned; very much the contrary; what I believe is that modern languages have no place in a college curriculum. They should be studied privately or as an elective study, and preferably in early youth. Furthermore, I also do not mean to imply that our present method of teaching the classics is particularly perfect. Indeed, the major part of the paper is a criticism of our present method of classical study.

I might say a few words on the origin of the paper. I have noticed for many years that in the higher positions connected with the electrical engineering industry the number of men who have risen without any college education is far out of proportion to what could possibly be the case if in the broad development of the mind the college were all that it should be.

Furthermore, during recent years we engineers have been impressed forcibly with the circumstance that we do not occupy in the public life of the nation the position that we should occupy, and must expect to occupy, due to the importance of our profession. We have complained that bodies appointed to deal with the relations of the states and the nation to engineering in its industrial and social aspect do not contain a single engineer. When considering the situation, thinking what I would do if I had to appoint such commissions, I was forced to conclude that I also would act in the same manner: I might appoint a man who is an engineer in spite of his being an engineer, but not because he is an engineer. This is an unfortunate situation. The cause of it was brought to my mind more fully by reading the paper presented by Mr. F. P. Fish last May,* not because of the contents of the paper, but because of its style and atmosphere, which is such that no mere engineer could have written it, but a classical scholar.

This is a matter which must be changed. We engineers must insist on occupying in the public life of the nation that position which is due to us as exponents of the most important branch of human thought and work. But before we can do

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**The Patent Situation in its Relation to Industrial Development*, PROCEEDINGS A. I. E. E., May, 1909, p. 441.

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and Romans had had our literature of the nineteenth century I doubt if they would have been more definitely impressed by the novelty and strangeness of that literature than we are by the classics when we read them.

It is a most healthful and broadening influence to become saturated with a mode of thought and a view of life so different from those with which our own experience makes us familiar. This works in many ways. In studying the life and literature of ancient times, we become more and more thoroughly satisfied as to the essential nature and capacity of man, which have changed very little during the period of recorded history, while at the same time we are deeply impressed with the different lines on which thought and action may develop in man's effort to hold his own against the forces of nature and to strive and prosper individually and in the community relation.

There is no doubt that one who studies the classics is better fitted for sane and wise views on all the social and governmental problems of to-day than would be the case if he relied only upon what he has seen or read of modern times. He surely becomes a better judge of human nature and better able to steer a straight and wise course in the affairs of life, where so much depends upon an adequate recognition of the wonderfully efficient but vacillating and unstable characteristics of man, whether regarded individually or collectively.

I feel the same as to the study of any literature of olden study of any early literature except that of Greece and Rome, as a preparation for an engineering career, and I am very much afraid that the balance of advantage may reasonably be said to lie on the side of ignoring even these in engineering institutions of learning, that there may be more time for things directly germane to the profession. The curriculum of an ordinary training school for engineers can not be made long enough for even training in the fundamental principles of engineering—which is carried none too far—and the application of those principles to practical work.

But it is a subject for regret that engineers can not in every case have the benefit of a first-hand knowledge of the classics. Some of them get such knowledge outside of school and many read the classical authors in translations, and thus get at least a shadow of the advantage that would come to them if they were to study the original tongues. Translations, however, are unsatisfactory and do not give the spirit of the original. More than that, the mere studying of Greek and Latin as languages, is, in my opinion, of far greater value than is perhaps generally recognized at the present time. Personally, I owe more to the work I did on the classics than to any other branch of my education. I agree that the same advantages do not come from the study of modern languages, but am not certain that under existing conditions I should go so far as to advise the elimination of those studies from the curriculum of a technical institute.

C. A. Adams: I wish to refer particularly to one sentence in Mr. Dooley's paper:

> The development of the boy and not shop production should be the watchword of the apprenticeship department of every company.

That is, in a way, a new attitude on the part of manufacturing companies. For many years they have been extremely interested in the efficiency of machinery, and have devoted much time, effort, and money toward the development of machinery to its highest efficiency; but that most important and most marvelous of all machines called man, has been for the most part neglected. It is refreshing to see this further indication of the modern trend towards a more intelligent and ideal coöperation.

In regard to Dr. Steinmetz's paper, I must confess to mixed feelings which are difficult to express satisfactorily. I have the greatest sympathy with Dr. Steinmetz's general point of view. I believe thoroughly in the value of a careful study of the classics for engineers as well as for men of other professions, but I cannot believe that this study is as vital as here described, or that it accounts for the difference noted between engineers and so-called "men of affairs." Is not this difference due rather to the fact that the *average* boy who selects engineering as a profession does so because his interests are more largely objective? He is more interested in things than in the money that can be made out of them; he revels in the laws of nature and a work for each type, and that it does not necessarily follow that one is higher than the other. The ideal education is that in which each type has full and free opportunity to develop naturally toward its maximum of usefulness and efficiency.

One other opinion that I wish to express is that the work and training of the real engineer are such as to fit him peculiarly for the solution of those numerous troublesome social and economic problems which are so much with us to-day. The work of the real engineer forces him to think clearly and accurately, knowing that he is to be judged not by men but by the results of his work as determined by the operation of invariable laws. He is thus more likely to acquire the habit of seeing these problems without bias of person or class and without the influence of custom or tradition; in other words, he is apt to be more fair-minded than the average man of affairs.

Anyone conversant with easily obtainable facts and statistics in regard to social, political, and industrial conditions in this country to-day, must certainly conclude that there are many legalized sources of unfairness which could be easily removed were it not for the tremendous influence of their beneficiaries, many of whom are men of affairs. I for one am of the opinion that the real engineer will have at least his full share in the removal of these sources of unfairness.

Farley Osgood: The thing that concerns me most is that apparently engineers are being trained for manufacturing or designing purposes only. As yet I have heard nothing of what problems that confront the operating engineer are unexpected; they come rapidly in quick succession; they may be of an entirely different nature one moment from the next. The operating engineer, primarily and forever must be a quick, and a correct thinker.

I cannot agree with Professor Adams that the narrowing down of a man's training is healthful for him, if he has to deal with broad and general problems. Mr. Fish certainly strikes the keynote in saying that young men upon graduation should be able to solve a given problem without difficulty. Without meaning in any way to cast reflections on our designing engineers, I must say that they do get into ruts. There is no question about that. They are so anxious to get ahead of each other in their line of competition, so anxious to become well-known specialists in various lines, that they seem to forget there is anything else going on in the world besides the designing of the particular type of apparatus to which they are giving their time. From the beginning the operating engineer has not only engineering problems to take care of but he has to meet the public; he has to handle the financial side of his problems; and finally, but not by any means the least of all, he has to put his subject in such a manner before his board of directors that they will give him money to spend for the benefit of the stockholders. I do not think that distinct training solely for mathematical or strictly engineering lines will help him in the final and last problem, which is to get money from people who do not understand the engineering business to put into that business. That is the most difficult problem, and the ultimate problem, of the operating engineer.

I see a good many of the young fellows when they graduate from college and make application to our company for employment. We have what we call our kindergarten course, and put the embryo operating engineers through an operating training. This course is not like Mr. Dooley's course, which is exclusively for manufacturing purposes; it is of the same general nature, only along operating lines. Every recently graduated engineer that I have met within the last five years, with very few exceptions thinks that he must go into the factory. His whole desire seems to be to know how to design and make machines. That is certainly advisable; he must know that at some time or other. But this tendency works hardships for the operators, in getting young men that are willing to tackle the general problems of commercial engineering or business engineering as soon as they get through college. My only explanation of it is that they have not been sufficiently broadly trained to think on general subjects. They feel insecure in taking a position that will make them think of a great many different things at once which have not come to them before, therefore they go to the manufacturing companies. Frequently after they have been with the manufacturing companies for some time they begin

the way in which a study is presented. There are numbers of instructors in the classical languages who do not have the slightest broadening effect upon the students, simply on account of the way in which the subject is presented. On the other hand, a well trained instructor can, in discoursing on even a technical subject, treat it in such a way that the student will be led to look upon it broadly, and at the same time be taught to view in the same way the other aspects of life. It is the personal contact with the instructor that counts. As I look back over the educational period of my own life I feel this very deeply—the training that helped to broaden my mind did not depend upon the particular subject I was studying, but largely upon the man under whom I studied.

John C. Parker: The profession owes a considerable debt to the men who are doing the work Mr. Dooley has told us of, in training non-technical men. The actual operation of this training may be local; the significance of the thing is not local, it is not vocational; it is work which is both national and vitally human.

In Mr. Dooley's modesty and generosity toward his students I think he may be doing himself and his collaborators some slight injustice. All of us who have had to do with educational work know how hard it is to keep students up to the mark. It must be particularly hard in teaching night school. It boots nothing to say that these students are the most ambitious among the men who are working hard in the day time. Of course they are, they would not undertake the work if they were not; but I have found by conversation with men who are carrying on this class of work that many of the young men who have all sorts of laudable ambition and who undertake to piece out their daily experience by definite educational processes in the evening, enter the work under a mistaken ambition. They expect to reap an immediate reward. When the period of disappointment comes to the student, it must work hardship for the teacher. Even with the fellows who are not disappointed the teachers must find that after 9 or 10 hours in the shop it is pretty hard to hold their interest and attention. The teachers too, have been working during the day time, and at night they are called on to use the utmost tact and judgment in bringing to the students under their care the real utility of the work.

D. B. Rushmore: What is education for, or what are people after when they seek to obtain an education? At a recent meeting of the Schenectady Section, Dr. Raymond of Union College said he had come to think that the object of life was to be an electrical engineer. He thought perhaps there might properly be introduced into it one other object—that the object of life was to live, and one idea of education was to teach men how to live. All of us have to give attention to other matter besides electrical engineering. One thought that is perhaps expressed more frequently than others is the elementary law of life—that

graduate of the technical school who has devoted 4 years exclusively to the tasks set by a university or a college. His theoretical training is presumably better and more complete than that of the man who has had only 4 years in a night school. Perhaps his practical training is not so great, but in the long run—and not a very long run either—we should expect the college-bred man to excel the other in point of position and standing in his profession.

Dr. Steinmetz contends, however, that in order that an engineer may reach his complete development, not only as an engineer but also as a well trained leader of thought and of progress, he must have something besides this engineering training. He must have a liberal education. However, we may not agree with Dr. Steinmetz that the study of the classics is the one, or even the best way in which to obtain this necessary cultural education. The study of the classics is of undoubted value, having been tested during all the years which have elapsed since the revival of learning. However, it is quite possible to overrate the value of the study of Greek and Latin, particularly as at present pursued, and, as I understand it, Dr. Steinmetz does not defend the ordinary methods of teaching these languages and the literatures which are expressed in them. I believe that an insufficient time devoted to Latin or more especially to Greek is, as far as cultural results are concerned, time merely wasted, since no mastery of the language such as is necessary for a true appreciation of its literature is gained thereby. To understand the genius and spirit of the literature of ancient Rome, it is necessary to be able to do more than painfully pick out a translation of the *Commentaries of Casear* or of the *Odes of Horace*. We should read a literature in a familiar language, preferably its original language, but we do not appreciate literature when we must translate it. That means a mastery of the language. I believe that, as ordinarily pursued, students do not obtain such a mastery of Latin or of Greek, and that consequently one end which is sought, namely, the absorption of some of the spirit and ideals of ancient people, as expressed in their literature, is missed. The resultant advantage which we obtain ordinarily from the study of Latin and Greek and which is by no means inconsiderable, arises from the mental discipline thereby undergone, and the knowledge acquired of the structure and vocabulary of languages which are fundamental, inasmuch as they underlie a large portion of our own language and a large percentage of the languages of modern Europe.

I believe the same thing applies to the study of the modern languages. The technical colleges at the present time commonly require a certain amount of modern languages for entrance, and introduce a certain amount of study of modern language during the course. In my experience I have found very few graduates of technical colleges who can pick up a piece of French

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be attained only by a very few. Probably all of us realize that such master minds as those of Mr. Fish, Dr. Steinmetz, and Professor Karapetoff would be broadly educated under whatever circumstances they might be trained, and wherever their lots might be cast. Most of us, however, are not blessed with such ability, and it is impossible to cover so large a portion of the field of education.

Even Dr. Steinmetz can cover only a small fraction of the world's knowledge to-day, and most of us must be satisfied with a much smaller fraction of that knowledge.

I believe thoroughly in a study of the classics, and I also firmly believe that this is possible to every engineering student, whether of Mr. Dooley's school, or of the sort that Dr. Steinmetz advocates. My suggestion as to the solution would be that the study .of classics may be done, at least partly, in one's own language. We can study the classics of English literature, at least, and the student of Mr. Dooley's school can get real benefit from them. I quite agree with the previous speaker that Latin and Greek, which are alone considered classics in a narrow sense, are of comparatively little value as taught in the majority of universities and colleges. Instead of imparting a training in mental facility, the training is largely a matter of thumb facility in handling lexicons.

I am reminded of a remark made by the Rev. Dr. Boynton. In speaking of the Cornell spirit, he said that Harvard stood for style, as ordinarily interpreted by college men, Yale stood for pluck, as claimed by Yale men, and that Cornell, as he understood it, stood for work. Dr. Boynton said he was prepared to acknowledge that Harvard stood for style and Yale for pluck, and he was also prepared to admit that Cornell stood for work. But, he said, he came from a little freshwater college that many people seldom heard of, a college that he thought stood for something that he had not heard mentioned during the evening, and that was for education. That college was Amherst.

In this discussion regarding the classics I would stand for English primarily. I would like, in designing curricula, to see more emphasis laid on training in English. This would certainly be very useful to Mr. Dooley's students. In studying the best English authors they can learn to acquire a knowledge of English which will be commercially useful, and at the same time they can learn something of the humanities and something of the philosophical side of life. The essential elements of an education as they occur to me at the moment are: 1. To learn to think. 2. To learn to express one's thoughts. 3. To acquire a fundamental knowledge of the general principles of underlying foundations of the work one expects to do. 4. The ability to find information required in connection with the solution of any problem which may be presented, and to put that information into presentable shape, and to reach a correct solution. 5. The ability to apply this general information in a commercial way.

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I believe that a study of Latin, such as is required for the ordinary college entrance examination is very useful as an aid in understanding the derivatives of many English words, and at the same time an excellent mental training, and that, added to such knowledge of Latin, one should have if possible, a speaking knowledge of French or Spanish, or both. Practically a knowledge of Spanish is of much greater value to the American engineer than any other language. Our relations with Cuba, the Philippines, Porto Rico, Central and South America, are so increasingly important, and there will be so many more opportunities offered for business relations with South America, and other Spanish speaking countries than with other foreign countries, that I regard the Spanish language as of utmost importance for commercial purposes. Latin will help with both Spanish and French, so that a moderate amount of Latin is useful from all points of view. Then either Spanish or French, or both, can be acquired by reasonable study preparatory to entering college, if possible, keeping up such study during the college course, and later in some way getting a speaking knowledge of such languages. That can be done by residence in a country to which the language is related, or living with engineers or others who speak the language, or in some similar way. However, it seems to me a given amount of time will accomplish more for the average engineer in acquiring a knowledge of the philosophies and amenities of life, or the channels through which we can contribute most to the world, if applied to other subjects than Latin and Greek.

I should advocate strongly the study of English continuously throughout the entire college course, say at least 2 hours a week. This study of English should in later years be a study of classical English, and of clear and explicit expression in English.

The entrance requirements mentioned by Dr. Sever might be advantageously modified by omitting the German requirement, and requiring only one language, either Latin or French. Our own language is based much more largely on Latin than it is on German—German derivations are few. As a basis of acquiring a better knowledge of English, Latin is much more useful for the ordinary engineer or ordinary man of affairs than is German. In the affairs of actual life there is not one graduate, I should say, in ten thousand who will have any occasion to use German. Furthermore, I should require a certain amount of study of such subjects as logic, mental philosophy, and principles of law. For non-technical studies we might take 2 hours of English and 3 hours of general culture subjects throughout the entire course. This would require omitting some of the more technical subjects, but if the object of education is to teach a man to think, and to teach him to express his thoughts, some of the more technical subjects can be omitted without detriment to his general education. If a young man is going into operating work a knowledge of the intricacies of machinery design is not of much use to him. It would be better if one could have a 5-year course, and spend 4 years in general educational work. including mathematics, physics, chemistry, English and general culture subjects, and then specialize as to extremely technical work in the fifth year, after the young man has chosen, to a certain extent, the direction in which his life work is to be passed. By planning such courses, it is possible to give sufficient of the general knowledge of electricity, for example. This fundamental knowledge can be acquired without going too much into detail, or into the abstruse mathematics or theories. These advanced subjects can be taken up afterwards as one's special bent leads or work requires.

George F. Sever: The subject of technical and engineering education is so large and voluminous that it is impossible to attempt to take up all the points that have been presented this morning and discuss them to a finality. At a three days' meeting in New York last week many professors and engineers discussed quite fully the subject of the promotion of engineering education. I think there was not a single new thought presented before that meeting that was concurred in by any two men. For instance, there were suggestions for a ten-year course, a nine-year course, and then all the way down to a one-year course for the training of engineering students. The University of Missouri has established a five-year course for engineering students. Leland Stanford University is endeavoring to establish a five-year course, the idea in all these longer

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Dr. Steinmetz's attention ,although undoubtedly he has already noticed it. At Columbia University in 1897 there was established a definite six-year course open to students preparing for the engineering professions. The student starts in the college and takes three years of a liberal education, which is arranged to include Greek and Latin, or any other language, philosophy, sociology, or any other subject recognized as giving liberal training. The last year in his college course includes all the subjects needed in the first year of his engineering course, so that when he receives his degree of A.B. at the end of three years he will be prepared to start in the sophomore year of the engineering course and pursue the latter for three years, and secure the engineering degree which the university gives at the completion of that course. We have thus established, and only after very careful consideration by the authorities, a six-year course, including all the so-called dead languages as well as the modern languages and the engineering training. Now, if a man enters when he is 17 years old, he will be 23 before he leaves the university, and he will have had this excellent classical training. But the question is, will he advance in the community as a high type of man more rapidly than the trained engineer who has not had this classical training? This is a subject that has been discussed many times, and we have not found that very many men are taking advantage of this six-year course, which includes all that fundamental training which Dr. Steinmetz considers the best for the rounding out of the engineer. It is my opinion, that the engineer after he has had this technical

White wants us to teach Spanish. This brings us up to the point mentioned by Mr. Osgood, that he wants men trained to manage corporations. If we continue introducing subjects we are going to have engineering courses 20 years long, and never graduate our men; and if we keep them with us too long they will become absolutely stale. We are drawn upon continually to inspire students, but like a storage-battery we get, at the end of the season, entirely discharged, and it takes a long time to again get back our inspiration to stimulate ideas in the men. We can only turn out an average product, although there may be certain stars in that product who will make distinguished successes in certain lines, but we cannot develop all the men for a particular interest. We give all the students in our engineering schools during the first year a perfectly uniform course on the engineering fundamentals, such as mathematics, chemistry, physics, drawing, etc., and in the second year they take calculus, analytical mathematics, quantitative analysis, and drawing, and other fundamental subjects. Then they begin to diverge more widely and take those subjects in the different courses which they will need in their future practice.

To accomplish this we require 18 hours of lectures and recitations per week, and oftentimes five and six afternoons devoted to laboratory and drawing room work per week. How to get in all the subjects which are considered so essential in four years I fail to see, and many of my colleagues entertain that same feeling. So that we are obliged to take the supply as it comes to us from many preparatory schools, require certain preparation for entrance, and then try to turn out the average man.

C. A. Adams: I must have expressed myself poorly indeed to be classed by Mr. Osgood as an advocate of a narrow education. This would seem particularly strange as I am now connected with and have been instrumental in bringing about the establishment of a school of engineering which requires a college degree of students seeking admission. The principal object of this plan is to encourage the laying of a broad foundation, and it is a fact that about one-half of the men seeking entrance to this school have been students of the classics, usually in their secondary school period where such study is likely to be most effective.

The point which I had hoped to make was that among the young men entering the engineering profession there are various types of mind, each with its particular field of usefulness and each requiring a different training for its best development; and that the lack of a classical training is not necessarily synonymous with a narrower education. This is much more true to-day than it was 30 years ago, owing to the greatly enlarged opportunities for the study of the literatures of other peoples than those of Greece and Rome, as well as for study in those vitally interesting fields of government, economics, social ethics, etc. I also wished to suggest the possibility that even

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pendent thinking, the very thing the lack of which Mr. Osgoo deplores.

Mr. Rushmore made one statement with which I wish to take issue—he said that the object of education is to enable us t provide for our own existence and for that of those who are dependent upon us. That may be one of the objects, but feel very strongly that more emphasis should be laid upon the fact that the great object of education is to develop and maintain a maximum of happiness. That maximum of happiness does not depend upon how much money you can earn, but it does depend upon whether or not we are working in that fiel for which our particular talents best fit us; in that field where we can contribute most to the society of which we are a part.

C. R. Dooley: The fundamental idea of the night schoo is to train all-round men, to make them able to use their minds and their hands, and as Dr. Steinmetz mentions in the opening paragraph of his paper, able to attack new problems whatever they may be, to solve them right, and solve them quickly the very first time they see them.

Professor Adams and Mr. Scott have both referred to the many different kinds of men, suggesting that there may be demands for many different kinds of education. With an increasing number of kinds of educational systems, the problem o early selection becomes increasingly more important. The parents, and the teachers in the common schools, should be able to direct the general trend of the higher education of children. That, I believe is the highest responsibility.

the fact that the instructors are fully informed on their subjects—the students respect the information they get as being as near as possible to truth—thirdly, which is by far the greatest reason, that the boy has worked long enough at his everyday tasks to appreciate that he needs what Mr. Osgood says he lacks, namely, the ability to think. He views life from the workman's standpoint. He knows that he needs to correlate his thinking abilities with the manipulation of his fingers. It is this complete appreciation of the situation that holds the boy down to business.

Geo. H. Gibson (by letter): Engineering projects are, and should be, undertaken primarily to serve human uses and they can be carried out on any considerable scale only by social, human means, as coöperation, conference, organization, salesmanship, and other agencies included within the scope of business and affairs. Therefore, worldly wisdom, practical psychology based on observation of and experience with human nature, is as worthy of any man's study as are steam, electricity, or steel girders.

Dr. Steinmetz directs attention to the precious records of human experience preserved in the literary productions of ancient Greece and Rome. But is he not carrying the point too far when he urges the study of Greek and Latin to the exclusion of French and German? The content of these ancient languages is available in more or less perfect English translations, and nothing more will ever be added. On the other hand, French and German literature grows day by day; and this is particularly true of technological literature which is, indeed, valuable to the engineer who is pushing ahead into new developments only so far as it is new. If one waits for it to be translated by the journals or by text-book compilers, he will remain always a year or two behind the times; and many excellent original papers and monographs are never translated.

Illustrating the value of foreign technical literature, the writer makes a practice of searching carefully the various digests and indexes, including several published on the other side, with a view to catching all new developments in certain lines. It is his experience that the amount of original information appearing in the German and French engineering journals is at least equal to, if not greater, than that appearing in the English and American engineering journals.

This is especially true as to lines that might be classified under mechanical engineering, including, for instance, such subjects as steam turbines, high-pressure and high-efficiency centrifugal pumps and blowers, chemical processes for water purification, heating and ventilating practice, steam condensers and accessories, etc.

This may be due to greater activity in research, or it may be due to less reticence among investigators on the other side in giving results to the public; but nevertheless the fact remains

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so far had not appeared in our own papers. So by carefu
following these foreign papers we are better able to keep
touch with what is going on next door. The most satisfact
way of doing this is to read or glance through the articles on
self rather than to trust to translations or abstracts. In or
to do this one must read French and German, which the
fore have a practical value to the engineer that Mr. Steinm
would seem to deny to the modern languages. Further, it
the writer's experience that in reading on a subject with wh
he is somewhat familiar the difficulties of a foreign vocabulary
greatly minimized and that, therefore, the acquaintance w
a foreign language which can be obtained in the usual colle
course will serve to good purpose. The technical terminolog
of French and English for example, are largely identical.

A. E. Kennelly (by letter): While wishing to endorse wh
Dr. Steinmetz has said about the value of the classics and
ancient languages in education, I think that he hardly d
justice to the corresponding value of modern language, and
submit that these also have claims to be recognized.

It is, perhaps, open to debate whether the modern langua
of Europe offer so great a range of variation in mental persp
tive, or in the working philosophy of life, as do the classi
but it can hardly be doubted that in ideality, poetry, hum
and subtlety of intellectual discrimination, the languages a
literature of modern Europe are on equal terms with the la
uages and literature of ancient Greece and Rome.

foreigners, which I have done, much to my personal satisfaction.

J. Dalemont (by letter): The paper by Dr. Steinmetz shows the importance of the question of classical education for engineers. The same question has been agitating the minds of Europe for some time past, particularly in France and Belgium, where there is a tendency to cut down the time devoted to the study of dead languages. This, however, should not be used as an argument against Dr. Steinmetz' contention, as it is quite possible that in these countries too much time has hitherto been given up to the classics.

There are two points on which I think, most people will agree, namely: 1. The elite of all cultured classes in any country should receive an intellectual training, which will allow them to meet on common ground, when discussing social, economic, and political conditions.

2. The engineer, of all men, can least afford to ignore social problems, because of his responsibilities, which are often greater than those of most men, and of the far reaching effect of his work, but particularly, because of his close connection with industrial activity, which is becoming more and more the centre of modern life.

From these two fundamental facts we may conclude that the

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tellectual elite, it would be an easy matter to decide upon curriculum which would be suitable for all. But such is the case. Very wide indeed, and justly so, are the ro leading to a college education, and the elite—based solely on result of work and effort, in accordance with the requireme of our modern spirit and the interests of society at large—is outcome of a slow process of selection and elimination am the thousands of young men who yearly set out on these roa Here arises the real difficulty in deciding this question of humanities.

Should every student be required to follow a course of stu which would be of benefit only to the few making up this eli Certainly not. The course of study should not be chosen the latter only, but should be adapted to the needs of ev student—whatever career he embraces. In retaining study of the classics, therefore, some effort should be made modernize the system of teaching them, so that they may be benefit in preparing the mind to face the requirements a responsibilities of modern life. To my mind, a college cou should not be considered as an immediate means of makin livelihood, as such a mission belongs more properly to the p fessional course.

The foregoing remarks are in no way opposed to the princi of classical education; they are merely intended to call att tion to the fact that the studies in connection with such education should be kept within certain limits. If at present moment there is a desire in Europe to curtail the stu seem injudicious to impose a classical course on all students indiscriminately. It might be beneficial, as is done in the colleges and lyceums in France, to allow the student the option between several combinations of studies, or again as in the German universities to allow him a certain liberty in choosing some of the courses which he is to follow.

Ralph D. Mershon (by letter): I entirely agree with Dr. Steinmetz that breadth of education is desirable. I agree that the study of the Greek and Roman civilizations will conduce to that end. But I do not agree that the study of Greek and Latin constitutes the most effective means of arriving at breadth of training or that such study will, in itself, lead to knowledge of the Greek and Roman civilizations.

The "average man" (that mysteriously elusive individual with whom we must necessarily deal in such discussions as this) who studies Greek or Latin, or at least the average American student of these languages, is kept too busy struggling with the intricacies of the language itself to get much appreciation of the subject-matter of the text. Such mastery of the language as he may achieve in a college course is not sufficient to make it an adequate vehicle for beauty of sentiment or depth of thought. Such appreciation as he attains of the art and literature and such knowledge as he acquires of the philosophy, religion and politics of the Greek and Latin civilizations come through studies supplemental to that of the languages; studies pursued in English and which could be just as well pursued without any reference to the Greek and Latin languages. The truth of this may be easily verified by comparing notes with those whose college courses have been along classical lines. That it should be otherwise, would mean the study of these languages to an extent hardly expedient for the average man, certainly not expedient for the engineer. This being the case, the broadening influence of Greek and Latin is confined, mainly, to the discipline resulting from the study of language as such.

In general, it seems to me much better to get the discipline through the study of modern languages, mathematics, and such other subjects as will give it and in the end leave the student with an equipment of value to him in after life—of much more value than Latin or Greek could possibly be. Such study, accompanied by studies in English bearing upon the Greek and Latin civilizations, would accomplish the result aimed at and in a manner much more satisfactory and expeditious than the study of Greek and Latin. This course is especially expedient in the case of the large majority of American technical students, who are limited as to means and must make every minute devoted to education count for its fullest worth. For those who are so inclined and have the time and means at their disposal, the study of Greek or Latin, or music, or art, or any other study the pursuit of which may be considered rather as a luxury than as a necessity in the matter of breadth of training or of

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science rather than the vastly greater amount of time necess
to memorization in the study of these languages.

I know one engineer in whose experience such "small La
and less Greek" as is his portion has been of little value; w
his experience with French, the only modern foreign langu
he has studied, is quite contrary to that ascribed to mod
languages by Dr. Steinmetz. His French has helped him
engineering work (and otherwise) in spite of the lack of pract
because all foreign works of value are not translated into Engl
or, at best, tardily. He has found scientific French easier t
any other kind, in spite of the technical terminology and t
I believe, is the experience of most other students.

Dr. Steinmetz speaks of the value of a broad education
fitting the individual

> To perform his duties as a citizen of the Republic during the sto
> times of industrial and social reorganization which are before us.

Here again I am in sympathy with him as to the end,
not entirely as to the means. Anything which may contrib
toward each taking his proper and intelligent part in the cha
which must come, is to be ardently desired. The first essen
requisite to this end is not broader training, but utilization
such training as may now be had. Until the intelligent
of this country, until the engineers—since we are addres
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study. A course of study, in itself of the narrowest kind, may be made broad by the administration and direction of a broad mind; a mind from which the student will unconsciously absorb that which will influence him to larger reading and thought during his college course, and give him such an impetus in this direction as will persist after he has left college. For breadth of training cannot be attained in the brief span of a college course, any more than can the mastery of any given subject; and the college course is, at best, but a preliminary training and guide to the later self-training and independent thought, leading to the desired end.

There are a number of other points in the paper open to question, such as the definition of education; the sweeping implication that engineering is the application of empirical science; the implication that the engineer is limited to a single avocation, and the statement that this avocation necessarily tends more to onesidedness than the avocations of men in other callings. But these are points beside the main issue.

The paper appears to me inconsistent, and to one unacquainted with the author might appear pedantic, in that, although addressed to those having presumably no knowledge of Latin or Greek, it contains a number of Latin and Greek citations and allusions, and ends with a Greek quotation.

C. P. Steinmetz (by letter): I am glad to be able to agree with most of the speakers, even with those who can find no use for the classics in the training of the professional electrical engineer. We do not need the classics if we take the narrow view that the purpose of the college is to train the human animal to perform the functions of a professional electrical engineer, just as we train some wild animals to perform some other functions or tricks. But in this case we should stop talking of college graduates as educated men. What I was aiming at was the education of the intelligent being to perform the duties of citizenship in the field of the electrical engineer.

If we desire to train boys to be professional electrical engineers then naturally, no matter how much we lengthen the courses, we cannot expect to produce at the same time competent designing engineers and operating engineers and consulting engineers and corporation managers and constructing engineers and commercial engineers, etc. That is not what I desire. It is not what Mr. Osgood wants, as I understand him, to have the college turn out operating engineers. What he complains of is the rather insufficient development of common sense and ability to think in the product of the present college, which results from the narrowness of the professional training. It is this defect which I desire to obviate by advocating a broadening of the education.

Mr. Rushmore has well expressed the purpose of education as being for the purpose of teaching the boy to live; that is, to get the highest satisfaction out of life in its relation to the human

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of success, is especially beneficial.

In my paper I have attempted to outline the situation a suggest one remedy, in the study of the classics. I do not to say that is the only one. There are other factors contrib to that broad education. To mention only one, since its e tional value is frequently not realized—college athletic have not attempted to suggest methods of accomplishin result, because I believe that the means of broadening the e tion will be developed with increasing rapidity by the acc tion afforded by the pressure from within and without the neering profession.

What I would like to see is a classical academic course i posed between the classical high school and the technical col and then to have the college work succeeded by a year of prac experience in a manufacturing or operating company—one of graduate work rounding off the education. This would 12 years from the entrance in the high school to the entranc master of engineering, into the profession. It is a long only 1 year less than that demanded by the German gymna and university. Very many boys could not afford it. are many that could afford it but do not avail themselv it; some due to the inherent desire of American boys to be independent and self-supporting as early as possible, when lack the experience and intelligence to realize the necessit education; others, because their parents have succeeded i without a college education, or with a very meagre educa and do not realize that what was sufficient in former times the world was young, will not be sufficient in the times tha

ence, however, that there is a comparatively
of heat between the various stator parts. This is brought
by the fact that the final temperature of the iron and coil
usually pretty much alike, no matter how the losses are
tributed between iron and copper.

If the interchange of heat were complete, the tests for
termining the influence of unbalanced voltage should be ba
on the total losses in the stator; that is, we should have i
two-phase motor $I_1^2+I_2^2 = 2\,I^2$, and in a three-phase mo
$I_1^3+I_2^2+I_3^2 = 3\,I^2$ where I_1, I_2, and I_3 are the unbalanced c
rents, while I is the normal rated current. If the tests w
based on this assumption, the effect of unbalanced voltage wo
not by any means be as bad as that indicated by the curve
the paper. The interchange of heat is of course not perfect
the practical result will be somewhere between the values gi
by the curves of the paper and curves based on the ab
equations.

Moreover, most motors are designed to allow for cer
irregularities in the working conditions and will stand a cer
amount of unbalanced current without any reduction in
rating. Another thing that tends to reduce the danger cau
by unbalanced currents is that the amount of unbalan
usually decreases with the load. It is, therefore, the smal
for the overloads; that is, for the condition for which increa
heating through unbalancing is the least desirable.

It is well to mention these facts, as it is just as undesira
to overestimate harmful effects as it is to underestimate th

The current of an induction motor may be considered to consist of three parts: 1. The load current. 2. The leakage reactance current. 3. The no-load reactance current. It is the latter current that is chiefly affected by unbalanced voltages. This may be best explained by referring to a single-phase induction motor. In this type of motor a field is induced by the primary in the direction of the primary-coil axle, while certain secondary currents in the light running motor carry the field around and induce also a field at right angles to the first axle. At no load the size of this field at right angles is only a few per cent smaller than the primary field, the difference being chiefly caused by the ohmic drop in the secondary. If, therefore, the primary is provided with a second winding equal to the energizing winding, but at right angles thereto, the field carried around by the secondary will induce in this winding a potential only a few per cent smaller than the impressed single-phase potential and shifted 90 degrees against it. If upon the second primary there is impressed a potential which is opposite and equal to the potential induced by the secondary, there will be no current in this second winding. The motor can now be considered to be a two-phase motor with unbalanced potentials impressed; and it will be seen that while the unbalancing of the potential is only a few per cent, the unbalancing of the magnetizing current is as much as 100 per cent. If we further decrease the potential impressed upon the second winding, the motor will furnish current to the line through this second phase, which then acts as a generator. If, however, we increase the potential impressed upon the second winding, this winding will take current, and the current in the two primary windings will be equal as soon as the two primary potentials are equalized.

It has been shown above that a 100 per cent unbalanced condition is obtained if the unbalancing of the potential is equal to the ohmic drop of the secondary. This means that for a given unbalancing of the primary currents the unbalancing of the primary potentials may be the larger, the larger the ohmic drop in the secondary. In other words, the tendency for unbalanced magnetizing currents in the primary may be decreased only by increasing the secondary resistance.

It is at once obvious that this means should not be used as a remedy, since the increased losses caused thereby in the secondary are more harmful than the usual unbalancing of the total primary current. The unbalancing in the load current and the leakage reactance current is not quite so serious as that of the magnetizing current. Moreover, I do not think the design of the motor has much influence in it. It might be suggested that since the no-load magnetizing current is chiefly affected by the unbalanced voltage, the unbalancing of the total current may be kept small by designing the motors for small magnetizing currents. While this is true, it is hardly of any importance in this connection, since the designer always re-

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It appears, therefore, that the only remedy that may be app
to unbalanced currents in the motors is to improve the
conditions. Precaution is advisable regarding the statem
made by the authors of the paper about the influence of
potential upon the torque of induction motors. It is sta
in the paper that the torque is directly proportional to the
tential; this statement is based on the assumption that the
of the current alone is limiting the motor rating. It sho
be remembered, however, that if the potential decreases,
core losses decrease also, and therefore larger copper losses
a larger current are allowable. For this reason it is diffic
to make any correct statement concerning the continu
torque rating. The usual statement, that the torque is prop
tional to the square of the potential, applies only to the start
torque and the maximum torque, and is approximately ri
for these cases.

A. E. Averett: I do not think that the statements made
conclusion 6 are correct. The ordinary condition of operat
in the case of induction motors is at constant voltage.
torque of an induction motor is proportioned to the squ
of the voltage.*

Regarding the balancing of induction motors. I ha
found the same thing in a number of tests. I would expr
it in terms perhaps a little different, as follows: a motor w
15 per cent unbalanced voltage will heat almost double wha
would at normally balanced voltage. It operates very mu

ohn C. Parker: I wish to call attention to the commercial phases of the feature of unbalancing brought out in the paper. Where isolated industrial plants are used the distribution is almost always by means of conduits wherein line conditions do not obtain to unbalance the voltage, and wherein heavy single-phase loads are not carried in the plant to unbalance the voltage. Where long-distance power transmissions are used there is a possibility of unbalancing of the phases. With central station companies the same thing almost always occurs, due to the carrying of lighting loads and single-phase motor loads. As a matter of experience, this current unbalancing in the different phases of induction motors has been found to be quite serious. Many of the transmission companies selling hydroelectric power incorporate into their contracts a clause requiring the balancing of the loads taken by the different phases; under such conditions, if a heavy motor load is carried and the voltage is unbalanced, the user of the power may be penalized by virtue of that fact. The motor struggles to deliver uniform counter electromotive force on all the phases, the line does not do equally well, and the difference must be made up in the circulating of wattless currents in some phases of the motor. So much for the matter of the purchase of power from a transmission line.

Taking the case of the ordinary distributing companies, distributing to retail customers. In the effort to improve the load-factor most of the central station companies are adopting a basis of power sale in which the customer having the better load-factor receives the better rate. To determine what the maximum demand is some form of indicator is used. Up to the present date the most commonly used maximum indicator is a meter or indicator depending on the heating effect of the current. The meter takes no cognizance whatever of the circulating current taken by the motor in its struggles to maintain mormal conditions, as to whether the circulating current is in one direction or the other. If the maximum demand meter unfortunately happens to be in the phase taking the high current, the customer is penalized; if in the phase taking the lower current, the company suffers. If maximum demand indicators are installed in all phases and read once a month, the conditions may change between readings, so once a month a customer might still be penalized as the meter records only the maximum demand which has been pulled.

I am aware, as we all are, that there are now under development maximum demand meters not depending on the current drawn by the line, but again the commercial consideration comes in that it is very desirable to penalize the customer whose demand is at a poor power-factor, and hence there are strong commercial reasons why a maximum demand wattmeter rather than a maximum demand ammeter should be employed. Hence we do not get away from the difficulty introduced by the fact that an unbalance of the phase angles or of the voltage

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relation of the torque to the voltage or anything else it is ne sary to state what torque is meant. There may be under sideration the maximum torque of the motor, that is, the to where the motor drops out of step and comes to a stand Or it may be the torque that the motor can maintain continuo with constant heating, the safe heating of the motor. torques are important. The maximum torque of the induc motor varies with the square of the voltage. To send a th phase locomotive over a long-distance railway with twenty cent drop in the line, trusting that the maximum decreas torque in an emergency will be only twenty per cent, result in disappointment, because the maximum torque d with the square of the voltage. Again, the torque which motor can maintain continuously at constant heating does vary proportional to the voltage, nor proportional to the sq of the voltage, because the heating depends not only on the rent but also on the magnetic flux, that is on the voltage. the voltage is increased, with the same current, the losses, thereby the temperature are also increased; to maintain same temperature the current must be lowered correspondin while at lower voltage the current can be raised. It wil found, then, that for the same heating of the motor, the maxin torque which the motor can carry varies with the voltage. torque is greatest at a certain definite voltage, while at a lo voltage as well as at a higher voltage the torque which the m plicated by the design of the motor, because not merely the total energy loss counts, but local heating must be considered. In one motor the loss of power in the coils may be more objectionable, because the heat cannot escape rapidly through the coil insulation. In another motor the coils and the iron may, through the entire range, maintain practically the same temperature; for instance, in a low-voltage motor. Therefore the relation is a more complicated one than appears at first sight; it depends on the design of the motor, the character of the insulation, its thickness, that is, on the voltage for which the motor is intended, etc. But speaking broadly, we must say that *the maximum torque of the motor varies with the square of the voltage*; that the *safe heating torque is a maximum at some definite voltage*; that the *unbalancing of the voltage is relatively harmless*, up to a certain amount, but becomes objectionable and harmful only when excessive.

Chas. F. Scott: This paper takes up an important and interesting feature of the induction motor. The basis of comparison, however, in which the normal current from one of the motor circuits is taken as a standard of comparison, is not a proper standard of comparison for ordinary practical operation, as has been pointed out by several of the speakers. There would be some danger, therefore, in applying the results given in the paper promiscuously to average circumstances. The practical point in operation is to determine whether a motor operating on a commercial circuit is getting into difficulty, and is going to have its safe operating conditions exceeded by an unbalancing in voltage. The safe capacity of the motor is not determined by the current through one of its circuits. That does not determine its temperature. Sometimes the heating of the motor is not the limit. It may be the regulation, the starting conditions, or something else. Some induction motors run at very low temperatures, so that a considerable unbalancing would not lead to an excess in the temperature conditions. The motor not merely receives more energy on one circuit than the other, but it may act as a transformer. Synchronous motors and induction motors upon an operating circuit tend to lessen unbalancing between phases and hence have an equalizing effect.

That motors differ among themselves in their characteristics should be taken into account before applying the results of this paper to every condition. Motors differ not only in their temperature distribution, but also in various other characteristics. When acting as an equalizer between unbalanced circuits a large motor or one which is a poor transformer may not have any trouble in equalizing, whereas a little motor or one which is an efficient transformer may over exert itself. The summary of my comments is that the tests, while interesting, are based on certain laboratory conditions which do not permit their indiscriminate application to practice.

H. L. Wallau: Referring to unbalanced voltage, I have in mind some readings taken in a case of trouble. A 110-volt, three-phase motor had been connected to a circuit consisting of two transformers arranged in open delta, one of them, however, cut over to a secondary voltage of 230 volts, and the other to 115 volts, so that the voltage applied to the motor was 230 volts across one phase and 115 volts across another phase, and 200 volts across a third phase. When this motor was started on its load, the voltage dropped in one phase from 230 to 220, in another from 200 to 196 volts, and jumped from 115 volts to 122 volts in the third phase. It confirmed the fact that motors will work as transformers when the supply voltage is unbalanced and fed back into the line.

S. B. Charters, Jr.: The only point I wish to make is in regard to the matter of torque. We probably did not make clear what we meant. Our idea was this: a man is operating a motor under such load that he is drawing practically the limiting current of the motor as far as heating goes. If, under these conditions the voltage is reduced, the torque of the motor will be reduced; that is, provided each time the full load current is considered as the limiting factor. As the voltage goes down, less torque will be developed; it will vary approximately as a straight line loss, as far as our results go, as represented in Fig. 7, curves A and B. However, as has been said, to a certain extent these are laboratory results, and that should be taken into consideration before applying them to commercial circuits.

As stated by Mr. Scott, the difficulty in starting is an important point, because it was a case of that kind which first drew our attention to the difficulties introduced by unbalancing. In a plant operating three-phase, certain motors at considerable distance from the transformers would not start without the rest of the plant, because under the conditions of unbalancing which existed at the plant they were unable at times to develop enough torque to start under load. With the plant operating, the other motors balanced these conditions so that these motors would operate. When they were operating alone they were unable to affect the transformer conditions sufficiently and were not able to start.

I. E. Hanssen (by letter): The results obtained by the authors of the above paper agree closely with observations made by others, as may be seen by comparing the results obtained with the value given on the attached curve Fig. 1 which shows results of tests on a fairly large commercial motor. Of course, different motors will behave differently, depending upon the ease with which heat is conducted from the hottest places to the cooler ones.

It should be borne in mind that in the majority of cases the amount of unbalancing existing in well designed circuits is very small. A very small number of cases are reported of troubles from this cause. The writer believes it would be a serious mistake to build motors designed to minimize the effect of voltage or phase unbalancing by increasing the impedance of the windings as such motors would have a low maximum torque, low starting torque, low starting efficiency, and probably low power-factor as well. All that is necessary and desirable is to take all reasonable precautions to prevent unbalancing of the circuits; that is, all conductors should be arranged as nearly symmetrical as possible and unbalanced transformer connections such as open △ and two-phase—three phase. should be avoided whenever possible.

It goes without saying that motors which are themselves unbalanced should not be tolerated.

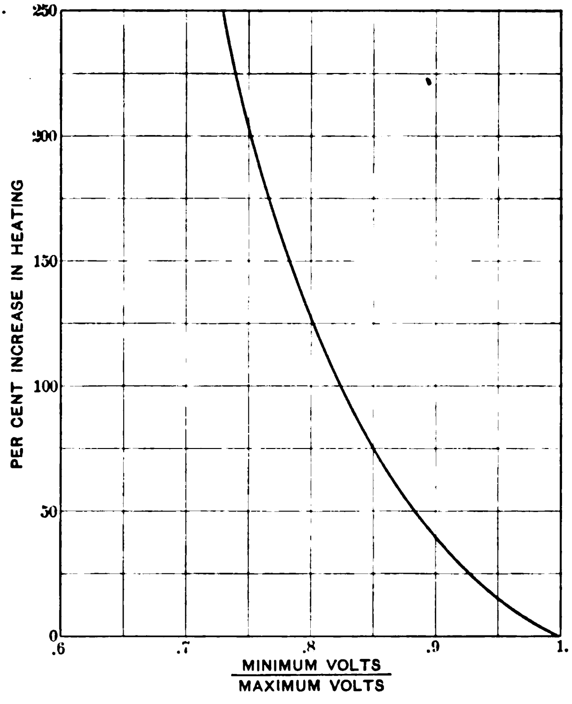

FIG. 1

Such inherent unbalancing of a motor may be due to an unequal number of turns in the different phases, improper angular displacement between phases, or to unsymmetrical end-connections, the existence of none of these causes being justified.

That circulating currents may easily be of such magnitude as to be very objectionable, will be seen from the following. Take the case of a machine which has two or more parallel circuits per phase displaced from each other by say 10 electrical degrees. Then the voltage tending to set up circulating currents will be approximately $2\,E \sin 5$ degrees $= 0.174\,E$, when E is the impressed electromotive force.

Assuming the short-circuit current at rated voltage to be six times full-load current, then the circulating current will be about equal to one-half the full-load current.

If the impedance of a motor and its supply circuit are known, it is a simple matter to determine approximately the amount of unbalancing for any given load and voltage or phase unbalance. As an illustration Fig. 2 shows a graphical method applied to a three-phase motor.

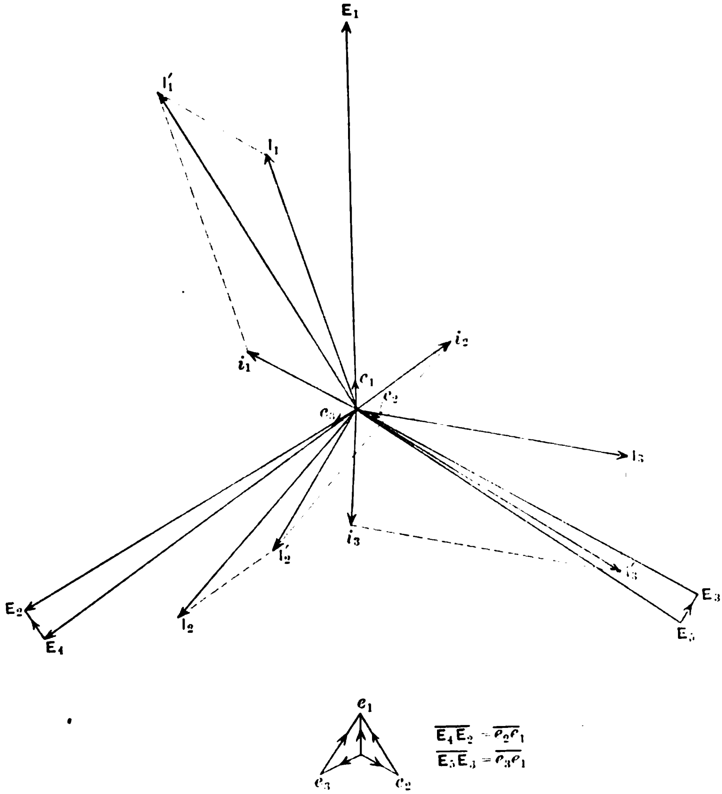

FIG. 2

E_1 E_4 E_5 = unbalanced impressed e.m f's.
E_1 E_2 E_3 = three phase counter e.m.f's. of the motor
I_1 I_2 I_3 = full load current on balanced circuit
i_1 i_2 i_3 = circulating currents due to e_1, e_2 and e_3
I_1' I_2' I_3' = resultants of normal full load current and circulating currents

The circulating currents i_1 i_2 and i_3 are inversely proportional to the sum of the motor impedance and the circuit impedance per phase and lag behind their respective e.m.f's. by angle $\tan^{-1} \phi = \frac{x}{r} = \frac{\text{rectance (inductive)}}{\text{resistance}}$

DISCUSSION ON "METHOD OF TESTING TRANSFORMER CORE LOSSES GIVING SINE-WAVE RESULTS ON COMMERCIAL CIRCUITS." FRONTENAC, N. Y., JUNE 28, 1909

(*Subject to final revision for the Transactions.*)

Frederick Bedell: The author is to be thanked for perfecting as an instrument that which, no doubt, more than one of us has already used as a method. We have used a calibrated transformer, whose losses under certain conditions have been accurately determined, for comparison with the transformer under test. Mr. Chubb's instrument will certainly prove most valuable if its calibration can be depended upon. Where one has a testing laboratory at his disposal he can readily check up such an instrument from time to time. When, however, one is remote from such testing facilities and has used an instrument of this kind for a number of years, a question arises as to whether it can be depended upon and will not be affected by time and temperature. I should like to hear from the author in regard to this.

Charles P. Steinmetz: In Mr. Chubb's paper a definition is given for the form-factor which I consider rather unfortunate. It is as follows: the ratio of the effective to the mean value. In this sense this term is frequently used, but it gives to the sine-wave a value of 1.11. Since in all electrical engineering we consider the sine-wave as the standard, it certainly is very unfortunate to define form-factor so that for the standard wave it does not give unity. Form-factor should be defined so as to give unity for the sine-wave. That is, *form-factor is the ratio of the effective to the mean value of the alternating wave, divided by the corresponding ratio of the sine-wave.* Hereby the sine-wave has form-factor 1, the form-factor of any other wave would directly represent the deviation from the standard wave, and the 1.6 power of the form-factor would be the correction factor of the hysteresis loss.

M. G. Lloyd: It seems to me that the instrument described ought to have a wide use, especially among smaller manufacturers and central stations where there are no facilities for getting sine-waves. I know of one case, for instance, which comes up in connection with some government work. The Navy Department in their permanent specifications for transformers at present requires the manufacturer who bids on their proposals to have the means of using and determining the sine-wave and control of the frequency. That prevents a great many of the smaller manufacturers from bidding on government contracts. An instrument like this would enable one to make tests without these facilities. If admitted by the Navy Department—I am told they are considering the use of such an instrument—it would be possible for a great many companies without testing facilities to participate in bids on such contracts. The difficulty of getting a sine-wave, as I have found by experience, is not at all small. In my paper on the "Testing of Transformer

Steel " I cite an instance of a generator which, to look at the oscillogram only, one would suppose gave a sine-wave. It had a very smooth and even curve and appeared to be perfect in all respects. An actual measurement, however, showed that the form-factor was considerably off. I take it to be a fact that it is not at all easy to get a machine that gives a form-factor sufficiently near to the sine-wave.

As regards the general use of these instruments, it is evident that the errors are only eliminated when the eddy currents bear a definite proportion to the hysteresis. Of course the errors in the instrument increase but slowly with variation of that ratio; but it occurs to me, in using it with widely different kinds of material, such as silicon-steel and the ordinary steel, that the same instrument perhaps could not be calibrated to read very well on both classes of material. While silicon-steel is in almost general use for certain classes of transformers, still, I understand, on low frequency many manufacturers still use the old variety of steel. Perhaps this is one thing that limits the use of the instrument.

As Mr. Chubb pointed out; I suppose the instrument could be supplied with different coils and calibrated to use on different frequencies, such as 25 and 60 cycles, which would make it of general application.

It seems unfortunate, too, that the instrument cannot be produced in a lighter form. Its excessive weight would hardly permit it to be classed with portable instruments, as it would not be convenient to carry such an instrument around.

L. T. Robinson: I wish to emphasize what Mr. Lloyd has just said about this instrument. It seems to me that it is a very good and very useful device, but is it not true that its application is limited to certain cases—to a line of transformers built, for instance, by certain designers for which they have prepared a suitable instrument? If such an instrument were trusted universally, would there not be found in commercial practice variations enough in the relation between eddy-current losses and hysteresis losses in transformers, and also variations enough in the form-factor of the waves, to make the results misleading?

Personally, I have used a method that amounts to about the same thing, but has not been worked up into combined instrument form. To a certain extent it is satisfactory but beyond that point it can not be trusted. I would prefer to see accurate work attempted in some other way; that is, by some instrument that would measure directly the form-factor based on which the correction would be applied to the transformer under test, either by separating the core loss of this transformer into its components or by using the somewhat definite knowledge that one would have of the constructive data.

Frederick Bedell: With reference to the definition of form-factor, I agree with Dr. Steinmetz that the present use is not the most logical. Form-factor as first used, following the lead of

Dr. Roessler in Germany, was defined as the ratio of the average to the effective value, which is the reciprocal of the value used in this paper. The form-factor of a square-topped wave is then unity, and of any other wave is less than unity, being 0.9 for a sine wave. This is in conformity with efficiency and power-factor, which have maximum values of 100 or unity, and proceed from these values down to zero. For a number of years form-factor was used by different writers in each of these two ways. Although the definition of Roessler has historical precedence, the definition of form-factor used in several papers presented to us at this meeting seems to be now nearly universal, and it is probably now too late to revert to the original definition or to make any other change.

Chas. F. Scott: This instrument is essentially a practical instrument. The scientific principles which have been explained, show that under a fairly wide variation of the very many variables which enter into the problem, it is substantially correct. To get a true idea of the value of the instrument, we must consider what must be done if this instrument were not available. Mr. Chubb has summarized the conditions which ordinarily apply, not only on the circuit of the operating company, but on the circuit of the manufacturing company in the testing laboratory. In order to get an accurate knowledge of the conditions of wave-form, it is necessary to make very elaborate, extended, and cumbersome measurements. It has been the custom at some factories to specify that a particular generator shall be used for supplying the current for transformer measurements and that the measurements are to be made on the machine when it is not loaded, it being known that the particular machine gives approximately a sine-wave. It recently happened that in a certain case transformers that were to be subjected to a certain test were measured with this new instrument, but it was found out afterwards that the generator, instead of being empty, as specified, was really carrying a load, and probably had a distorted wave form. In the days of the old method of measurement, with an ordinary voltmeter, there would be an error of probably twelve to fifteen per cent. The transformers, which had already been sent to the shipping room, were taken back and remeasured, and it was found that the measurements, under the corrected conditions, the specified conditions of the test, showed practically the same results as those formerly taken. Those who are the most familiar with the difficulties involved in the measurement of transformers, either in a large factory or at a remote station, will probably be the first to appreciate a method which is as good as this, although it may not be correct to the highest degree of refinement.

Charles P. Steinmetz: This instrument is extremely useful. We must realize, however, that in the usual case of transformer testing, where only a small amount of power is required, and therefore the efficiency of supplying the power is immaterial, we can get an almost absolutely perfect sine-wave from a circuit of any kind of wave shape, in the following manner. (Fig. 1). Suppose we have at *D* a supply of alternating voltage of known pressure and frequency, but of any kind of wave shape, no matter how distorted, and insert two inductances of equal reactance, *x*. into the circuit, and shunt a condenser, *C*, across the circuit, adjusting the condenser for the same reactance, *x*, as the inductances, so that if there is a short-circuit at *B*, there will be a minimum current from *D*. Then, connecting a resistance *r* across the circuit, and tapping off this resistance, a part of it or all, at *S*, any apparatus connected across *S*, if the current taken by it is small compared to the current in the resistance, *r*, receives a perfect sine-wave. There is a case of resonance in this combination which eliminates everything but the fundamental sine-wave. This arrangement may be useful, at least for calibrating such a core-loss voltmeter; otherwise, after a year or so it may be doubtful whether the meter is correct or not.

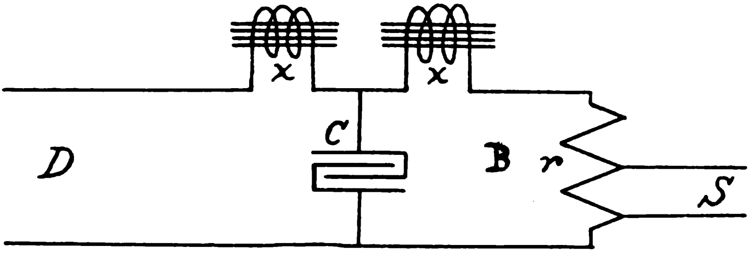

Fig. 1

L. W. Chubb: Answering Dr. Bedell as to the reliability of calibration. We have used the instruments since March, 1908, and have had remarkably good results. Constancy of calibration was obtained by making the steel core of the instrument of laminated steel rings of non-ageing material, without air-gaps and by thoroughly impregnating this core in a hard gum. Repeated calibration has shown the instruments to be reliable.

There is great need of such a method and instrument, as very large transformers cannot be even approximately tested by the usual method on the small generators that must be used for testing purposes. The new designs of transformers with silicon-steel cores, and their peaked exciting currents, will invariably distort the voltage wave of the testing generator, and unless the core-loss-voltmeter method, or the more complicated correction method, is used, the core-loss test is practically worthless.

Dr. Steinmetz suggests that the definition of form-factor be changed so as to give unity for the form-factor of a sine-wave. This would be a great convenience. The present method of having 1.11 as the sine form-factor introduces fractional coefficients in the usual formulas.

Dr. Lloyd speaks of the present government specifications for equipping and method of testing transformers, prohibiting the small producers from taking contracts. Such has been the case, but satisfactory specifications can certainly be written requiring the use of the core-loss-voltmeter, which will allow the small producer to compete, and which will greatly simplify the tests of the larger companies. Table III and the oscillograms in this paper show results of tests made by the Navy Department with a view of adopting the method.

In regard to different metals which may be used in the transformer core. It makes practically no difference whether the transformer under test is built with sheet-iron, open-hearth, or silicon-steel. The same instrument can be used and the result of core loss will in all cases vary from the true sine-wave value much less than if the root-mean-square voltmeter is used. The curves of Fig. 5, show the errors introduced by different ratios of eddy and hysteresis losses. A general statement, with no figures, was made in regard to the effect of steels having different exponents of hysteresis. Suppose we take an example of an extreme case to show the effect of the variation of hysteretic exponent: Assume a form-factor of voltage of 1.20 hysteretic exponent of instrument core 1.6; of transformer 2.0; sine-wave core loss of transformer 80 watts hysteresis, 20 watts eddy loss, 100 watts total; sine-wave loss in instrument 16 watts hysteresis, 4 watts eddy current, 20 watts total. On the peaked wave the voltage must be raised 6 per cent to give the required voltmeter indication and input of 20 watts to the instrument. At this point the input to the transformer will be hysteresis 76.910 watts, eddy current 22.472 watts, total 99.382 watts. Indeed, it will be seen that the component hysteresis and eddy-current losses are very much in error; but one is practically as much low as the other is high, so that the sum is only 0.6 per cent in error. In this case we have considered the hysteretic exponents in instrument and transformer differing as much as will be found in service, and the error of less than 1 per cent is commercially allowable.

In regard to the portability of the instrument, it is certainly heavy as now made, but a much lighter instrument is being designed which will be quite portable.

Mr. Robinson expressed the opinion that it can be used only in certain cases. The experience we have had with the instrument shows clearly that such is not the case. Any transformer of a certain frequency which is of commercial design may be tested with any core-loss-voltmeter, adjusted for that frequency, and in all cases, it may be said that the core loss tests will be more accurate than with the usual voltmeter.

L. T. Robinson: I agree substantially with everything that has been said, that is, for ordinary conditions, but I do think the instrument should be used with considerable caution, because there are variations in form-factor on systems—that might sometimes make it misleading to use an instrument like the one described.

L. W. Chubb: You mean that the purchaser of a transformer does not want to know the core loss on a form-factor of 1.11, but that he is interested in what the loss will be on his line.

The transformer which has the lowest loss on a sine wave will have the lowest loss on the customer's wave. Specifications and tests should all be based on the same wave, and then guarantees and test results will be directly comparable. The manufacturers do not know the form-factor of the customer's line. If they did it would not be practicable to work out special performance guarantees for the customer's circuit. It is far better to have a standard wave shape on which to base the performance, and require that the tests be made in terms of this standard wave, or sine wave. Such tests can be made with the iron-loss voltmeter on any commercial circuit.

The next question referred to the proportion of eddy current and hysteresis loss varying in the instrument. The percentage of hysteresis does vary at different scale readings, but within a readable range the ratio is sufficiently constant to give accurate results.

It was also suggested to use an instrument to find the form-factor and make corrections in the observed core-loss result. It should be remembered that if this is done it is necessary to make several elaborate tests and calculations, while with the iron-loss-voltmeter it is only necessary to adjust the voltage until the meter reads the normal value, and then read the core loss directly on a separate wattmeter.

Dr. Bedell suggests having the square type wave or the unity form-factor wave as standard, and then comparing other waves to it; in fact, treating the matter as in the case of power-factor. The unity power-factor is the most desirable and convenient reference value for the cosine of the angle of lag or lead, while the unity form-factor is a limiting as well as a maximum value, and a condition which is never acquired in the usual alternating-current circuits.

Dr. Steinmetz speaks of using a harmonic filter, as shown in his diagram, for obtaining a sine wave for testing transformers or calibrating the iron-loss-voltmeter. The scheme will give a sine wave at *S* at no load, or when the current drawn at this point is very small in proportion to the current through the resistance. However, a transformer exciting current is a distorted low-power-factor current with a decided peak, when the values of voltage are low or going through zero. On account of this distorted and low-power-factor current there will be out-of-phase resistance drops in the resistances shown, which will peak the voltages at *S*.

The scheme outlined by Dr. Steinmetz could be used in calibrating meters taking very small current, but I believe the iron-loss voltmeter takes too much current to be successfully calibrated by this method.

In reply to the question concerning the form-factor correction scheme, I will say that oscillograms were not taken. However, voltage drops and currents were observed at the cell and at other points of the circuit. We found experimentally that the relative readings of the root-mean-square- and iron-loss voltmeters, connected to the terminals of the transformer, could be easily and quickly adjusted by means of the inductance *L* and resistance *R*, thus making the form-factor correspond to a sine wave, a peaked or a flat wave.

DISCUSSION ON "ELECTROMOTIVE FORCE WAVE-SHAPE IN ALTERNATORS." FRONTENAC, N. Y., JUNE 30, 1909

(*Subject to final revision for the Transactions.*)

J. C. Lincoln: I would like to ask Professor Adams if he has any particular pitch winding to recommend in order to give the best results in eliminating these higher harmonics?

C. A. Adams: The curves of Fig. 9 show the reduction of the various harmonics for all pitches above 50 per cent. The pitch that reduces the larger harmonics most effectively is a pitch of 10 slots in 12; it reduces the 5th, 7th, 17th, and 19th harmonics to about one-quarter of their value in the full-pitch winding. The 3rd, 9th, and 15th can be entirely cut out by star connection. This leaves only the 11th and 13th harmonics with their full pitch magnitudes, and these are usually small.

J. C. Lincoln: A pitch of about 84 per cent then?

C. A. Adams: Yes; approximately.

A paper to be presented at the 240th meeting of the
American Institute of Electrical Engineers
New York, November 12, 1909.

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(Subject to final revision for the Transactions.)

THE ELECTRIC SYSTEM OF THE GREAT NORTHERN RAILWAY COMPANY AT CASCADE TUNNEL

BY CARY T. HUTCHINSON

The first three-phase installation on a trunk line railway in the United States was put into operation early in July of this year at the Cascade Mountain tunnel on the Great Northern Railway, in the State of Washington, about one hundred miles east of Seattle.

I purpose in this paper giving a general description of the plant with especial reference to the electric locomotives, together with a brief statement of its operation for the short period since it has been put into service; this record will of necessity be somewhat sketchy, as there has not been sufficient time to accumulate full data for the various conditions of operation that will be met with in service, especially the performance during winter.

In general the plant comprises a hydroelectric generating station, operating under a head of 180 ft., having a capacity of approximately 5000 kw. in generators at 6600 volts and 25 cycles; a transmission system operating at 33,000 volts, delivering energy to a sub-station where it is transformed to 6000 volts, at which pressure it is supplied to the overhead conductors and to the locomotive by way of an overhead trolley; on the locomotive the pressure is reduced by three-phase transformers to 500 volts for the supply of the four three-phase motors with which each locomotive is equipped.

The Great Northern Railway crosses the Cascade Mountains through a tunnel 13,873 ft. long; this tunnel is on a tangent and has a uniform gradient of 1.7 per cent; rising to the tunnel from Leavenworth, on the east, the ruling grade is 2.2 per cent, and

21 per cent of the total distance of 32.4 miles from Leavenworth to the tunnel is on the ruling grade. From Skykomish on the west to the summit the ruling grade is 2.2 per cent, and 44 per cent of the distance of 24.8 miles is on the ruling grade. Fig. 1

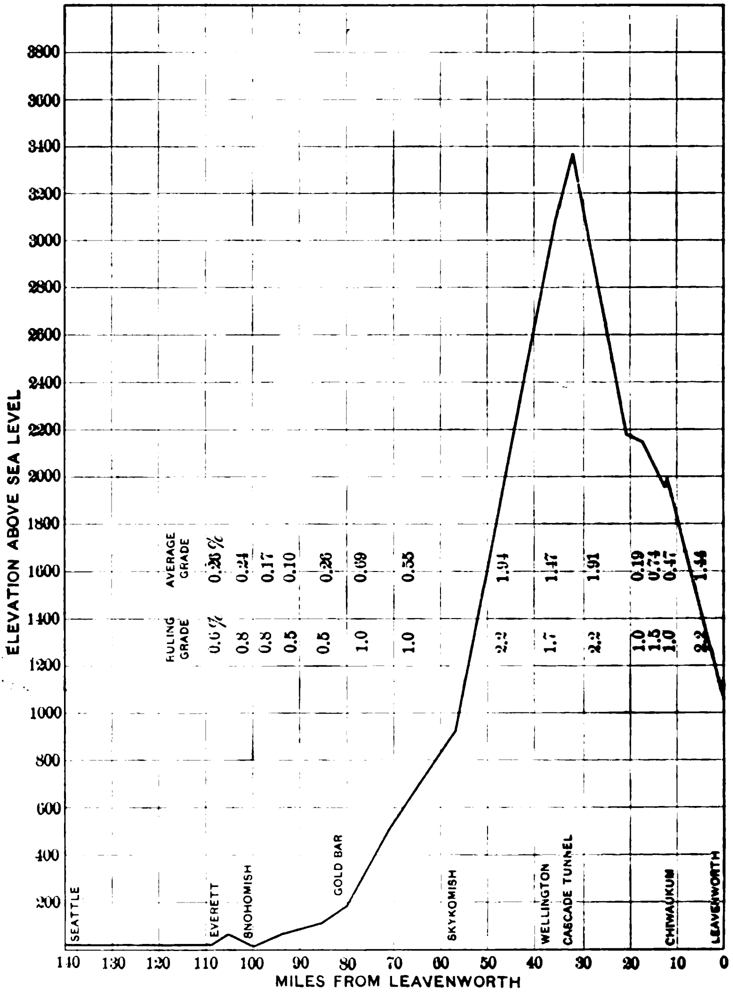
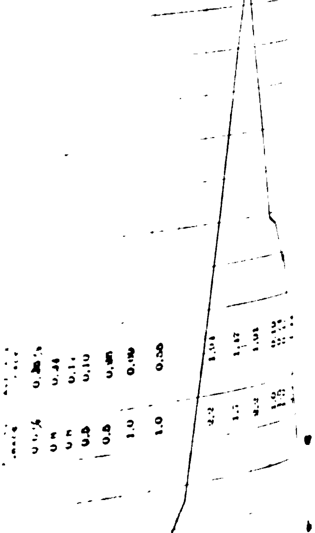


Fig. 1.—Profile of Great Northern Railway—Leavenworth to Seattle

shows a condensed profile of this section of the road; the average up grade from Skykomish to Wellington is 1.94 per cent and from Leavenworth to Cascade, 1.37 per cent.

The operation of the tunnel with steam locomotives was at



hour for the tunnel to clear itself of gases, but on days when wind was changeable, the passage of the gases from the tu would be stopped by the change in the direction of the w and they would pocket. Under such circumstances, wor the tunnel was very dangerous. There are refuge cham containing telephones every quarter of a mile, but it w difficult matter to keep these instruments in order, on acc of the gases, smoke, and moisture.

The tunnel is lined with concrete throughout its length, is in good condition. The roof is practically dry. The en tunnel drips more or less from condensed steam just after passage of a train, but is comparatively dry at other ti The temperature changes at the top of the tunnel are very ra varying from atmospheric temperature to several hun degrees fahr. from the heat of the locomotive exhaust. these reasons this tunnel is the limiting feature to capacity of the Great Northern Railway for hauling freight ac the mountains.

Mallet compound engines are used on this division, at the head of the train, and one pushing. The moun selected, on account of its greater simplicity and less cost. The choice of the system to be used was under consideration for more than a year; the three-phase system was finally decided on, plans were prepared, bids obtained, and the contract for the four locomotives let on June 22, 1907.

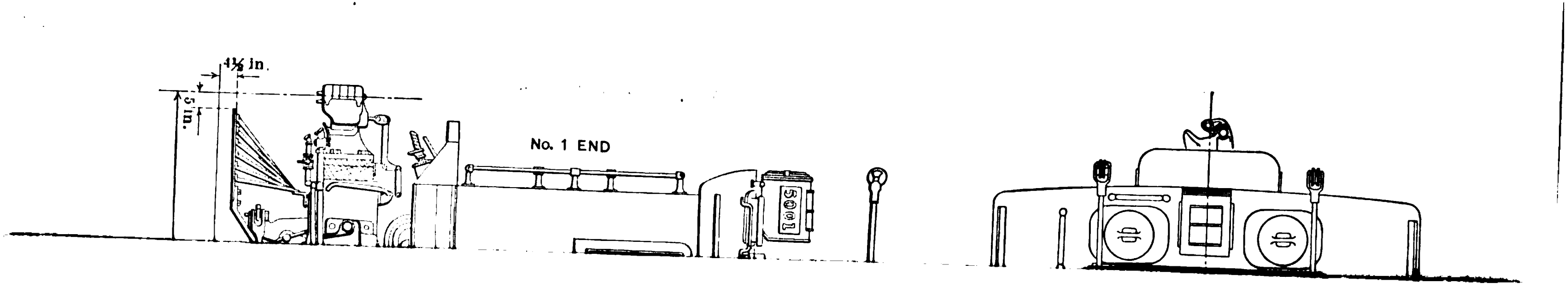
The original problem was to provide equipment to handle a train having a total weight of 2000 tons, excluding the electric locomotives, over the mountain division from Leavenworth to Skykomish, a distance of 57 miles. The system was to be first tried out at the Cascade Tunnel.

The tractive effort required to accelerate a train having a total weight of 2500 tons on a 2.2 per cent grade, using 6 lb. to the ton for train resistance and 10 lb. to the ton for acceleration, making a total of 60 lb. to the ton, is 150,000 lb.; this would require four locomotives of a tractive effort of 37,500 lb. each. The railway company's engineers limited the weight on a driving axle to 50,000 lb.; therefore four driving axles per locomotive are needed, giving a coefficient of adhesion of about 19 per cent. This is a measure of the maximum power required. The locomotive was, therefore, designed to give a continuous tractive effort of approximately 25,000 lb., and it was expected that four would be used with a train maximum weight. But the locomotive as built greatly exceeds this specification.

General Design of Locomotive

The locomotive as built is shown in Fig. 2. The principal data of locomotive are as follows: total weight 230,000 lb. all on drivers; two trucks connected by a coupling, each truck having two driving axles; a three-phase motor connected by twin gears to each axle; gear-ratio, 4.26; diameter of driving wheels 60 in.; synchronous speed of motor 375 rev. per min. giving a speed of 15.7 miles per hour at no load, dropping to 15 miles per hour for a load corresponding to the one-hour rating. The motors are wound for 500 volts and are completely enclosed and air-cooled; clearance between stator and rotor, ⅛ in.; trolley pressure, 6000 volts; each locomotive has two three-phase transformers reducing the pressure from 6000 to 500 volts, arranged with taps so that 625 volts may be used on the motor.

The distribution of the total weight of the locomotive is as follows:


4½ in.
5 in.
No. 1 END
5001

Total.......	
That is,	
Total weight per axle....................	57,500 "
Dead weight per axle....................	18,500 "

The specification of the motor required an output of 250 h. continuously for three hours with 75 deg. cent. temperature eleva tion, when supplied with not more than 2000 cu. ft. of air per mi ute. The test results of the motor show a continuous output of 37 h.p. at 500 volts with 1500 cu. ft. and 400 h.p. at 625 volts,with th same air; the one-hour rating of the motor at 500 volts wi 1500 cu. ft. of air per minute is 475 h.p.; the ratio of continuo output to the hour-rating with 1500 cu. ft. of air is therefore 7 per cent. The continuous output at 500 volts corresponds to tractive effort of 9350 lb. per motor and the one-hour outp to a tractive effort of 11,900 lb. per motor; the locomoti will, therefore, give 37,400 lb. tractive effort in continuo duty, or 47,600 lb. tractive effort for one hour. Fig. 3 sho the characteristic curves of the motor, at 500 volts.

Calculations from the profile of this section give:

Westbound, Leavenworth-Cascade

Average up-grade....................	1.37 per cent

These figures assume the train to be moving continuously and are based on 6 lb. per ton train resistance, as are all calculations herein unless otherwise stated.

The average power of the locomotive when pulling will then be 1.12 kw. per ton, and therefore each motor can carry 250 tons in continuous service on this mountain division, assuming there are no stops and no opportunity for cooling; or each locomotive could haul (4×250 – 115) = 885 tons trailing load, if the power requirements were continous; as there are necessarily stops, the rating as determined by heating is somewhat greater than this.

The locomotive has been tested to a maximum tractive effort of nearly 80,000 lb., corresponding to a coefficient of adhesion of nearly 35 per cent; with 60,000 lb. or 26 per cent, each locomotive can accelerate the train of 885 tons trailing on a 2.2 per cent grade, using 60 lb. per ton as the total tractive effort; or, in other words, the train that a locomotive can haul, as determined by the average duty and safe heating limits, is just about equal to the train that it can accelerate on the maximum grade; that is, the average capacity of the locomotive and its maximum capacity are in the same proportion as the average duty and maximum duty. The design is well balanced.

Making some allowance for these figures for the sake of conservatism, the rating of the locomotive on this division can be put at 750 tons trailing load.

ELECTRIC EQUIPMENT OF LOCOMOTIVE

Each locomotive is equipped with four three-phase induction motors, wound for 500 volts at the primary or stator; the motors are completely enclosed and are cooled by forced air circulation from a large blower. They are suspended from the axles in the standard manner, except that they are geared at both ends of the armature shaft; this was made necessary by the low speed and high torque required, as it was not considered safe to use a single pair of gears. The gear had 81 teeth, the pinion 19 teeth, giving a gear ratio of 4.26. The gears are of specially hardened steel; in order to secure perfect alignment the two pinions on each shaft were cut simultaneously. At first it was the intention to use some form of spring connection between motor and driving wheel, but this was subsequently abandoned, as it seemed that there would be sufficient flexibility in the armature shaft to take out any small differences between the two sets of gears. As far as can be told at present, this assumption appears to be correct, for there has been no difficulty with the gears and no unequal wear. The gears run with little noise and the construction seems satisfactory.

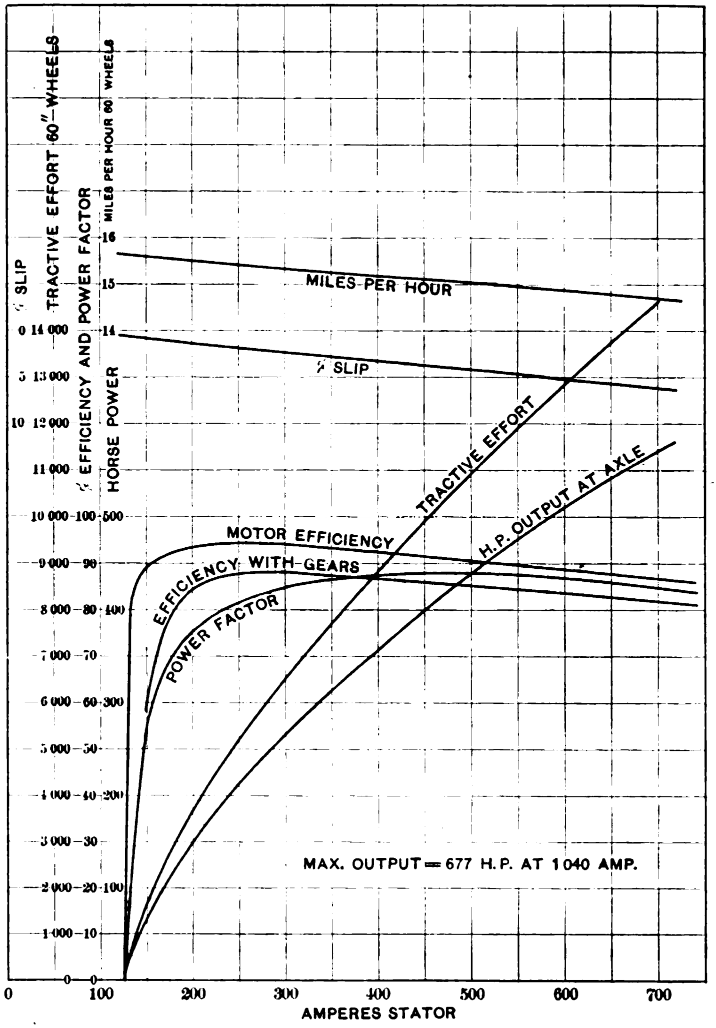


FIG. 3.—Characteristic curves of Great Northern three-phase 475-h.p. 25-cycle, 500-volt motor—gear ratio 4.26; 60-in. wheel

The locomotive carries two three-phase air-blast transformers, having a nominal rating of 400 kw. each, transforming from 6000 volts to 500 volts normally, or to 625 volts by the use of taps. The continuous capacity of the transformer is not as great as that of the motors, although it is fully up to the specification, and it may be that the quantity of air to the transformer will have to be increased when the locomotives are put in continuous service.

Compressed air for the brakes is supplied by two 100-cu. ft.

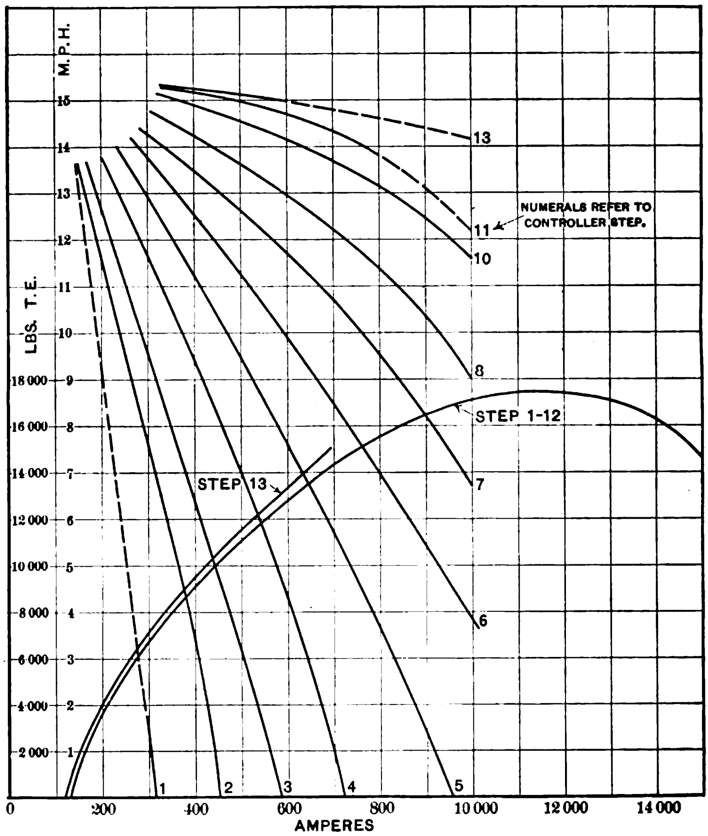
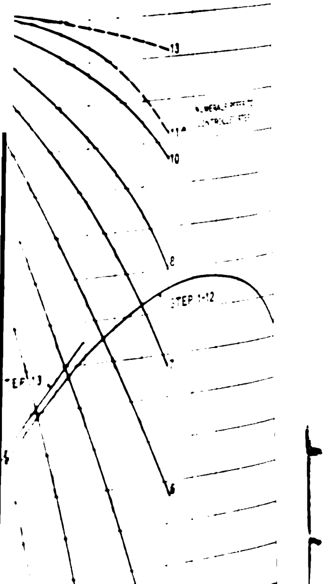


FIG. 4.—Speed-torque curves of Great Northern three-phase motor on the various control steps

induction-motor-driven compressors; the cooling air is supplied by a 9400-cu. ft. motor-driven blower. The locomotive is equipped with a combined straight and automatic air-brake system.

Control system. The control system of each motor is separate; the circuits branch from the transformer and are independent



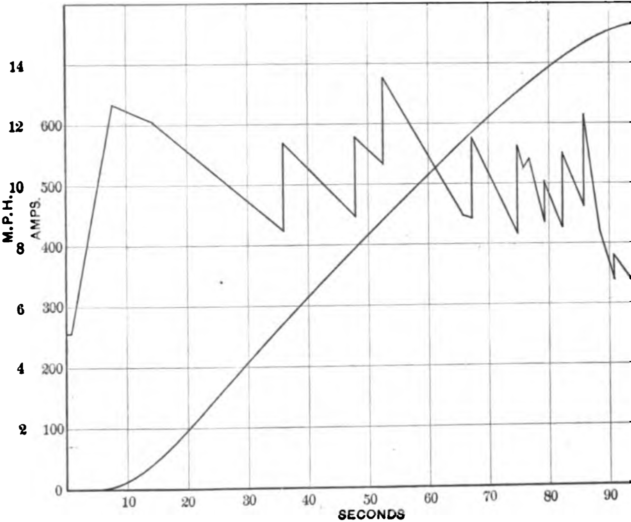


FIG. 5.—Acceleration curves

Tractive effort for locomotive—44,400 lb.
Acceleration—0.177 miles per hr. per sec.
Equivalent to a trailing load of 555 tons on a 2.2 per cent grade

three values of the torque of the separate circuits. The principal advantage of this is that 56 contactors do the work that would otherwise require 128, thus effecting a great gain in the simplicity of the control apparatus.

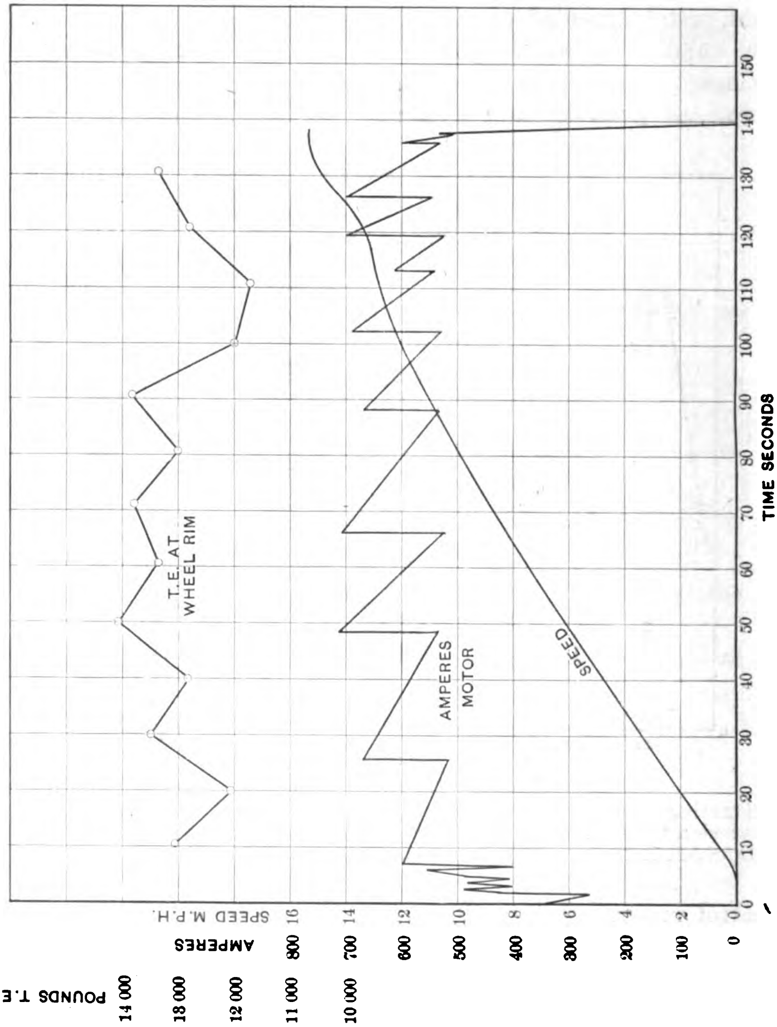


FIG. 6.—Acceleration curves
Tractive effort for locomotive—52,000 lb.
Acceleration—0.12 miles per hr. per sec.
Equivalent to a trailing load of 735 tons on a 2.2 per cent grade

Experience with the locomotive in service indicates that the initial torque, which is approximately 20,000 lb., is somewhat high, and I am now having the control changed so that on the first step two motors only will be thrown in circuit, and on the second step all four motors. This change is readily made by eliminating step 12, which tests have shown to be of little or no value. Fig. 4 shows the speed and tractive effort of the motor on the different control steps, with unbalanced circuits, and on the final step, without resistance.

Many acceleration tests were made at Schenectady, generally using one motor. Fig. 5 shows the result of one of these tests, in which the average tractive effort was 11,100 lb. per motor, corresponding to 44,400 lb. for the locomotive. Fig. 6 shows a similar test in which the average tractive effort was 13,000 lb. per motor, corresponding to 52,000 lb. for a locomotive. Fig. 5 is equivalent to accelerating a train of 555 tons on a 2.2 per cent grade at the rate shown on the curve; that is, 0.177 miles per hr. per sec. Fig. 6 represents the acceleration of a train of 735 tons on a 2.2 per cent grade at the rate there shown, that is, 0.12 miles per hr. per sec.

MECHANICAL DESIGN OF LOCOMOTIVE

The locomotive is of the articulated or hinged type, having four driving wheels on each half of the running gear and is without guiding wheels. The running gear is not two independent trucks coupled together, but is more nearly comparable to the Mallet type of steam locomotive, in that the hinged sections are so rigidly connected that they tend to support each other vertically and guide each other in taking the curves, although the hinges are designed to offer minimum resistance to lateral flexure. There are no springs to prevent this flexure, and the wheel base is free to accommodate itself to any curvature; the effect of this guiding action is to minimize the flange wear, as in the Mallet locomotive.

The equalization system takes advantage of the vertical rigidity of the truck to distribute the spring stresses over groups of springs instead of concentrating them on single springs; the truck section on the one end is side equalized, but the section on the other end is carried on a three-point suspension. The springs are thereby equalized in groups and the groups are so arranged as to eliminate all skew or twisting stresses in the truck frame.

The framing of the running gear is of substantial steel castings annealed and held together by body-bound taper bolts in reamed holes. Side-frames are castings of truss pattern; end-frames and bolsters are steel castings of box-girder type; the end-frames and all parts are designed for buffing stresses of 500,000 lb. Bolsters are hollow castings and form part of the air reservoir for the motor ventilation; the air is supplied to the motors through a hollow centre pin. The wheels are 60 in. in diameter with removable steel tires 3.5 in. thick. The wheel-centres are steel castings. The gears are shrunk on an extension of the wheel-hub, thus eliminating the torsional stresses from the locomotive-axles. The motors are connected through gears at both ends; that is, they are twin-geared to the driving wheels; this has the advantage of maintaining accurate alignment between axles and armature shaft.

The cab is carried on the trucks through centre pins on each bolster, the centre pin on one end having a slight longitudinal sliding motion to allow for variation in the distances between truck centre-pins in taking curves. The cab extends the entire length of the platform and is made of No. 10 steel plates which carry a monitor that supports the trolley base and has a ventilated opening running through the centre and perforated side plates to permit the escape of air from the interior of the cab. The greater part of the control apparatus, the rheostat, the transformers, contactors, etc., is placed in a separate compartment 60 in. wide and 22 ft. long, enclosed by steel partitions extending directly up to the monitor roof. This leaves two open operating spaces at the ends of the locomotive, connected together by two side aisles 30 in. in width. This centre compartment is divided into three parts by steel-plate partitions, the middle part contains the high-tension apparatus, including switchboard; the end parts are duplicates, each containing one transformer and the contactors for two of the motors. The rheostats are placed in the monitor at the top of the cab. The air for ventilation, after passing through the transformers, cools the rheostats and then escapes to the atmosphere. Placing these rheostats at the top of the cab has also the advantage of raising the centre of gravity of the locomotive, which is nearly 60 in. above the rail head, higher than is usual with electric locomotives.

GENERATING SYSTEM

The energy supply for the locomotive is derived from the Wenatchie River, which flows along the line of the railway for a distance of some 20 miles. The power house is located about 2.5 miles west of Leavenworth. There is a low concrete divert-are twin-geared

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and the contactors for two of the moto

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tank at the corner of the power house, having a total heig
183 ft. above its foundation. The tank proper is 30
diameter, and with a storage height of 54 ft. above its
spherical bottom gives a storage capacity of approxim
38,000 cu. ft.

The pipe line leads directly into the upright pipe of the
tank, which is 8 ft. in diameter; within the upright pipe
waste pipe having a diameter of 3 ft. 2 in., extending 7 ft.
the level of the crest of the dam; in the tank the waste p
expanded uniformly to a diameter of 7 ft. 6. in, thus affo
a circular weir of 23.5 ft. in length.

The power house is designed for three main units an
exciter units. There are now installed in the power hous
main units, each turbine rated at 4000 h.p., directly conn
to a three-phase alternating current.

The two main units now erected, with the exciter, r
approximately 500 cu. ft. of water per second when operat
full load of 8,000 h.p., giving a velocity of flow in the pe
of 8.7 ft. per sec.

The extreme low flow of the river at the dam is estima
be 380 sec-ft. The small pond formed by the dam has a s
capacity equivalent to 8000 h.p-hr., for a depth of one foot
wn three feet. The

25 cycles; these machines are designed to have very large overload capacity, and operate at a low flux density.

There are two exciter units, each having a nominal capacity of 125 kw. at 750 rev. per min. These units also have a large overload capacity; they frequently carry 150 per cent overload, on account of the very poor regulation of the water wheels. A third unit, identical with the first two, has been ordered.

The power house also contains four transformers for raising the pressure to 33,000 volts, each of a nominal capacity of 833 kw. but guaranteed to operate 100 per cent overload for one hour, with a low rise in temperature. Three of these units are in service, the fourth is kept as a spare.

The switchboard apparatus is of the usual type, having panels for the generators and the feeders, and is provided with the usual measuring instruments.

One reason leading to the use of the three-phase system was the possibility of regeneration; that is, of returning energy to the system on down grades. With the present installation it is obviously not possible to make any use of the energy so returned, but in order to prove this practically an automatic rheostat controlled by the speed of generator was installed in the power house; when a train on the down grade reaches a little more than the synchronous speed, the electrodes of the water rheostat are automatically lowered by an amount proportional to the difference between synchronous speed and the speed of the generator; this throws a load on the system and acts as a brake to the train. The operation of this apparatus is entirely effectual.

The nominal capacity of parts of this equipment, in particular of the transformers, may seem unusual; but it must be remembered that the plant is intended to operate on a load having extreme fluctuations, the entire load being on for, say, 15 minutes and then off for two or three hours, and consequently the transformers can be made small.

This plant has operated satisfactorily with the exception of certain troubles with the water wheels; in particular, the generators have shown ability to hold their rated pressure under extreme variations of speed, due to the effective control of the Tirrill regulators. The generator fields, designed for 125 amperes, have frequently carried 300 to 350 amperes, and the regulators have held the pressure normal, in spite of fluctuations of 35 to 40 per cent in speed.

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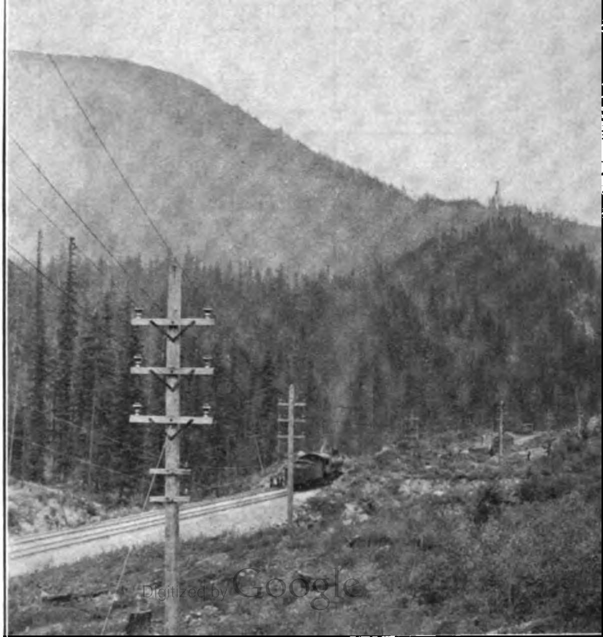


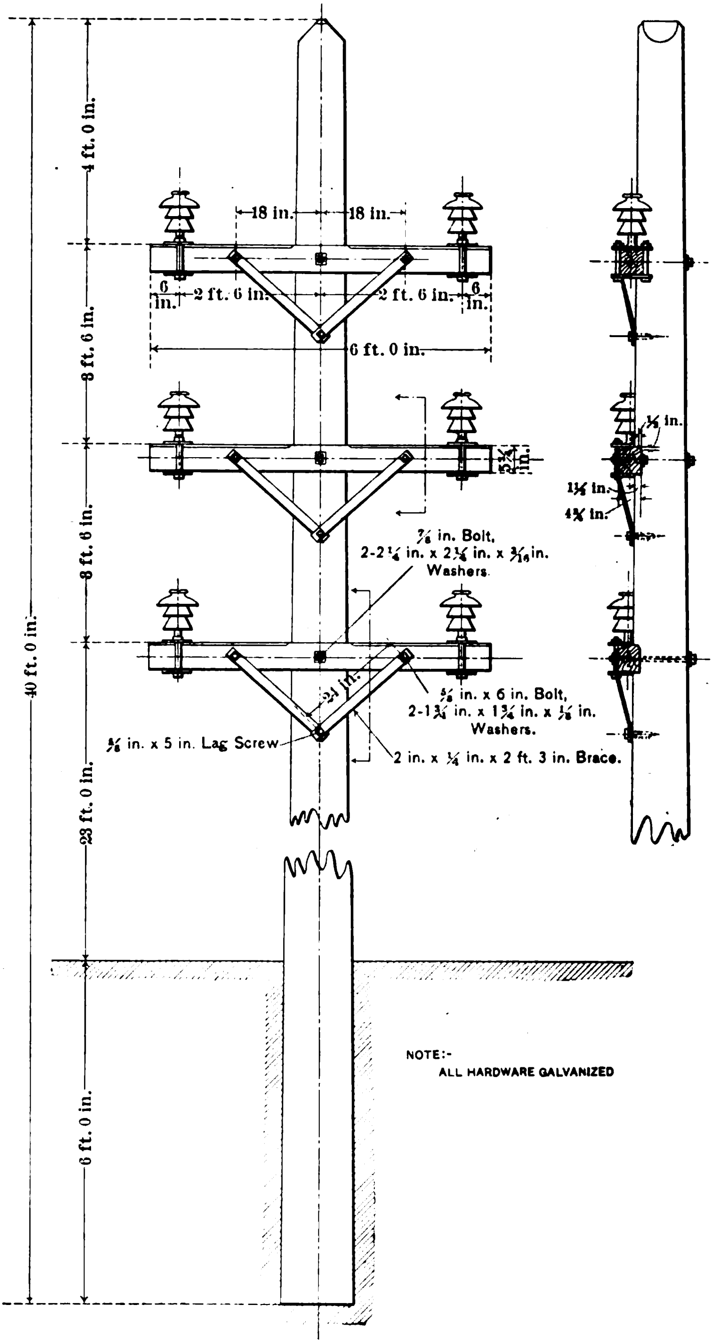
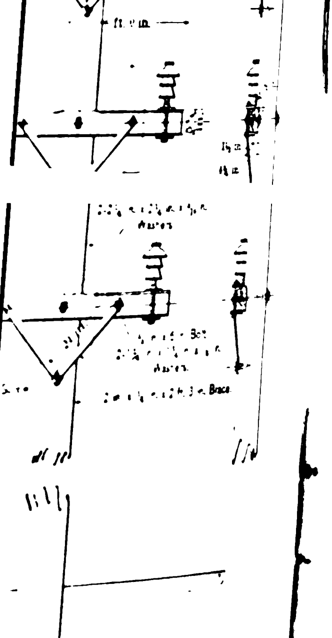
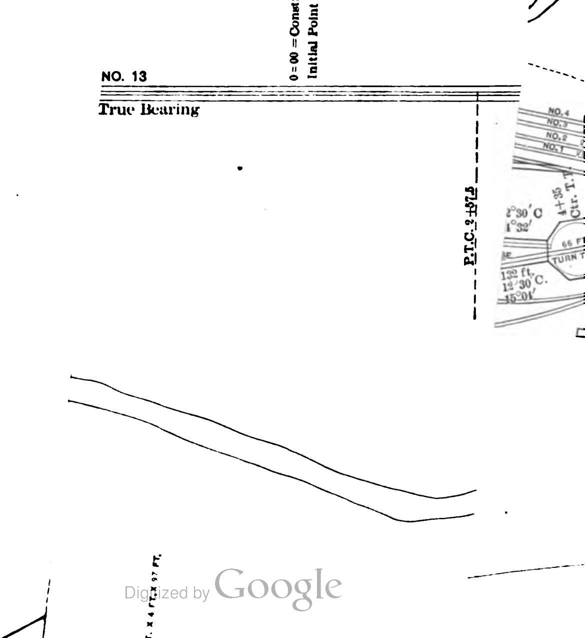


FIG. 8.—Standard pole of transmission line: two 33,000-volt circuits of No. 2 B. & S. gage wire


Brace


0 = 00 = Const
Initial Point
NO. 13
True Bearing
P.T.C. 2 + 37.5
NO. 4
NO. 3
NO. 2
NO. 1
4 + 35
Ctr. T. T
2°30′ C
1°32′
66 F
TURN T
132 ft.
12°30′ C.
15°01′

reason a comparatively low line pressure is used.

The telephone line is carried on the same poles; the tran mission line is not transposed, but the telephone line is tran posed at every fifth pole.

The construction of this line was completed a year ago, and has stood through one winter, during which there were more tha thirty snow and rock slides; only one of these slides cause damage to the line, and in this case only one of the two circuit was interrupted; it could have been repaired within an hour The same slide interrupted the operation of the railroad fo eight to ten hours.

Sub-station. The sub-station is at Cascade, practically at th east portal of the tunnel. Three single-phase transformers ar in service and a fourth in reserve; these transformers ar duplicates of those in the power house. The equipment of the substation is along the usual lines and calls for no special comment. The low-pressure bus-bars at the sub-station are connected t the overhead wires in the Cascade yard and also to the Wellingtor feeder, which runs through the tunnel to the extreme end of the Wellington yard.

Tracks electrified. Fig. 9 and 10 show plans of the two yards. In both yards the main track and two side tracks are electrified with the necessary crossovers, etc. The total length

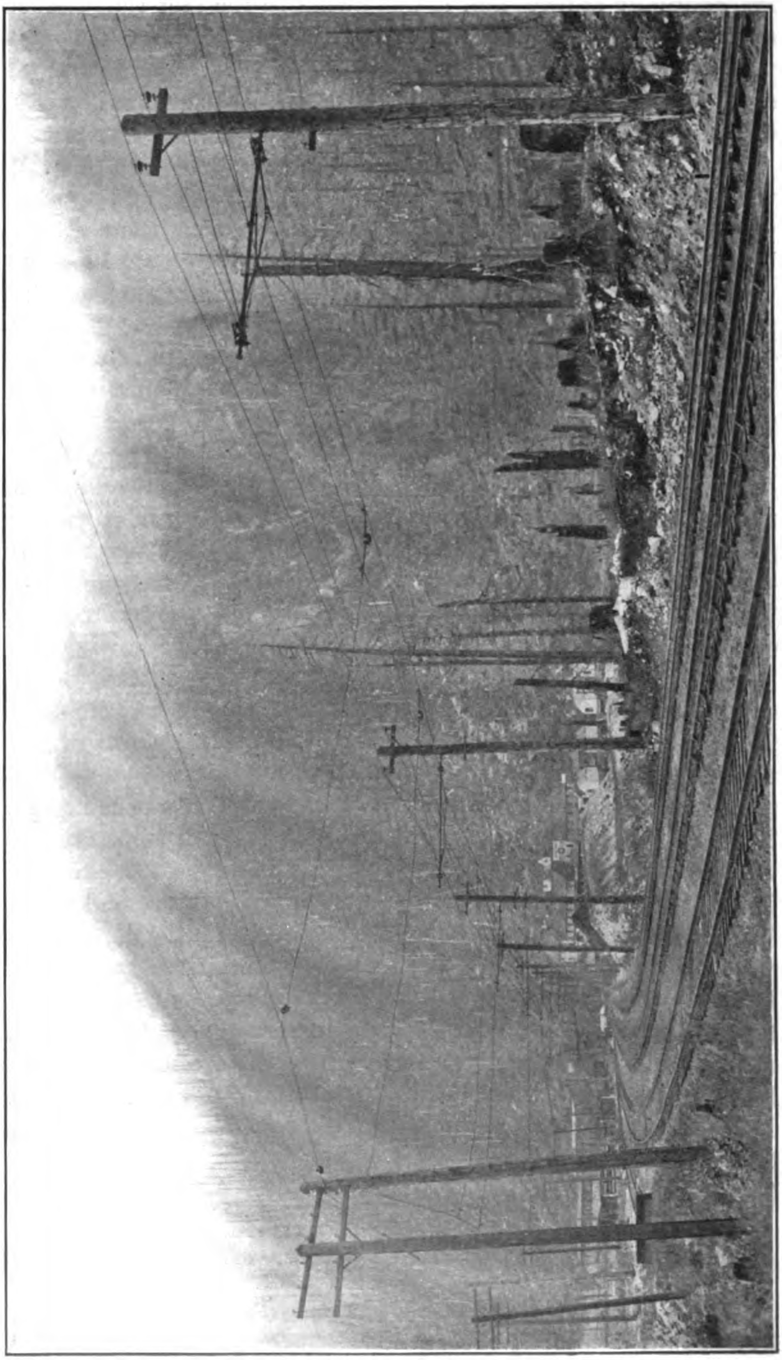


FIG. 12.—Overhead construction in Cascade yard, showing bracket construction at curve

construction in Cascade yard, showing bracket construction at

obstructed the space between adjacent tracks.
supported at intervals of 100 ft.

Multiple track supports consist, for each phase, of a ste
span supported by and insulated from a cross-cater
span, both spans being secured to cross-arms on the pole
means of porcelain petticoat strain insulators; the spans for
two respective phases are three feet apart. The wires of the s
phase, for the different tracks, are insulated from each othe
means of wood breaks and porcelain link insulators, in serie

In the case of brackets, each phase is insulated from gro
by means of a wood break in series with a porcelain petti
strain insulator.

Where wires of opposite phases cross at turn-outs, they
insulated from each other by section insulators made of
and about five feet in length; four insulators are used,
connected at one end to a special 8-deg. crossing pan and a
other end to one of the four wires converging toward the cros
Except for one track whose wires are cut straight through
crossing pans without section insulators, it is necessar
switch the controller to the off position when the trolley
passes under the insulators; methods of avoiding this have
considered and are being tried out.

Heavy steel bridges, Fig. 14, forming anchorages for

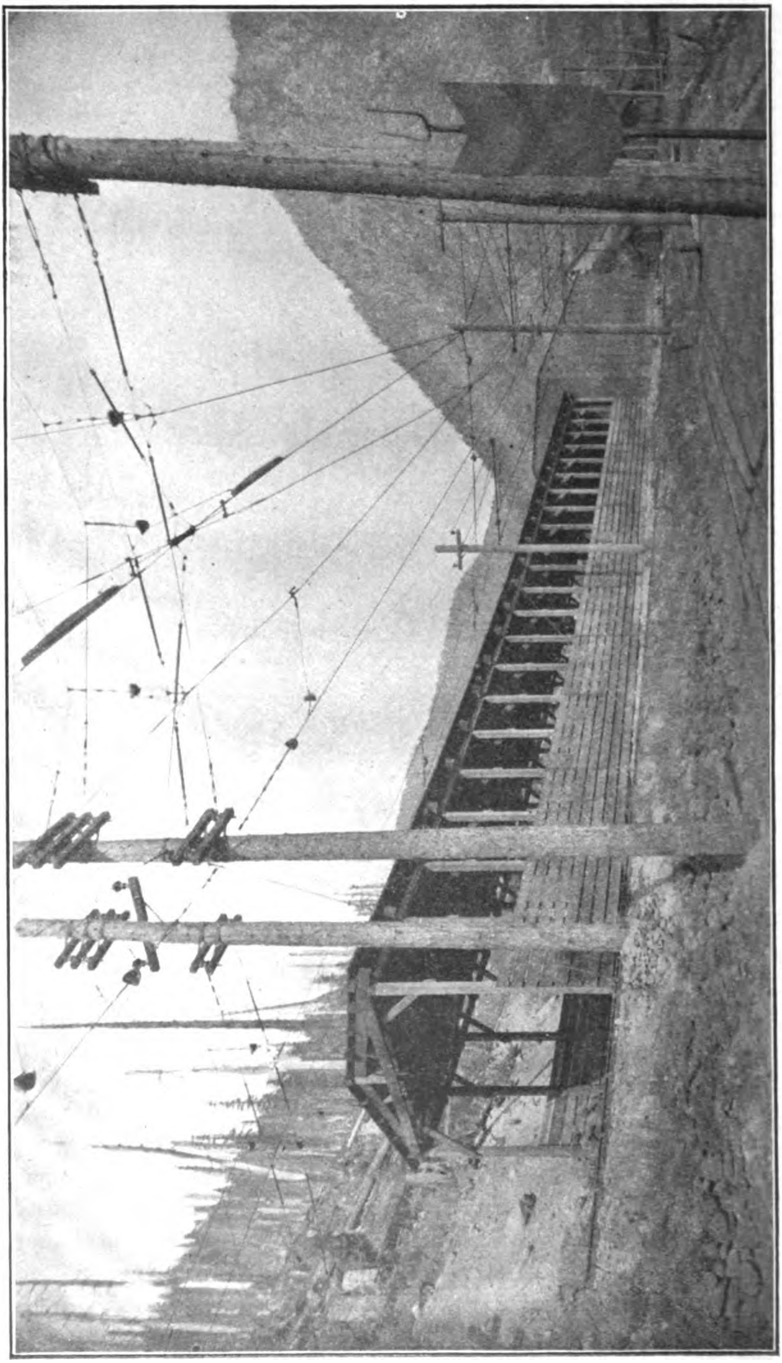


Fig. 13.—Cross-catenary construction in Wellington yard at switch point

This construction is shown in Fig. 21, 22 and 23. Fi gives a cross-section of the tunnel and shows the location trolley wires, trolley feeder, the wires for the lighting cir and the telegraph and telephone cable. Fig. 22 shows a section of the method of supporting the trolley wires, and F shows a longitudinal view of the trolley suspension scheme however, does not show the swiveled connection of the to the clamp holding the trolley wire at the lower end. necessity for adding this swivel connection was shown b breakage of several studs.

In the tunnel the wires are 17 ft. 4 in., above the of the rail and 8 ft. apart; the latter spacing enables train to operate the hand-brakes, or walk on the tops of freight the construction being such that head-room in not inter with. Each wire is supported every 50 ft. by means of a 1 Detroit clamp attached by swiveled connection to a stud w is in turn swiveled to the middle point of a turnbuckle. two eyes of the latter, by means of strand wire, connect to a link and petticoat strain insulator arranged in series two petticoat insulators being secured to the roof of the tu by means of two expansion bolts, about 5 ft. 6 in. a Anchors and side-braces for the wires in the tunnel ar cated at intervals of 3000 ft.

Practically all metal work in the tunnel supports is copp

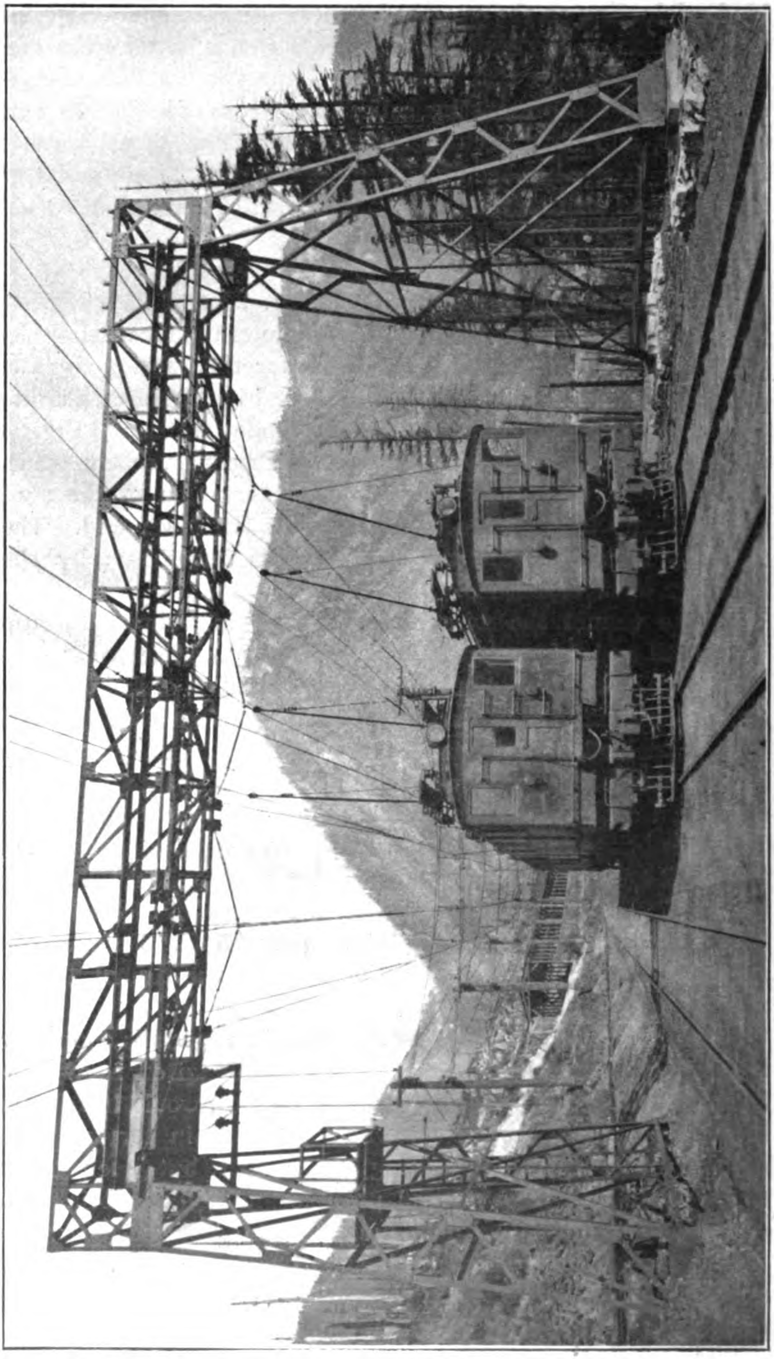
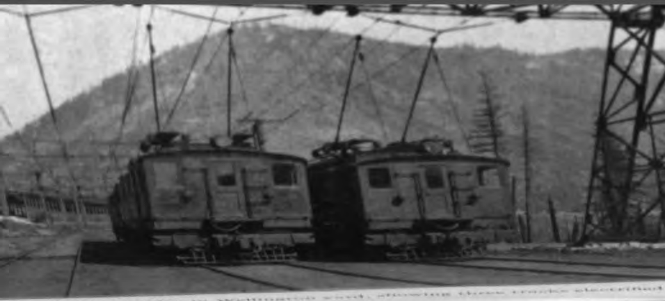
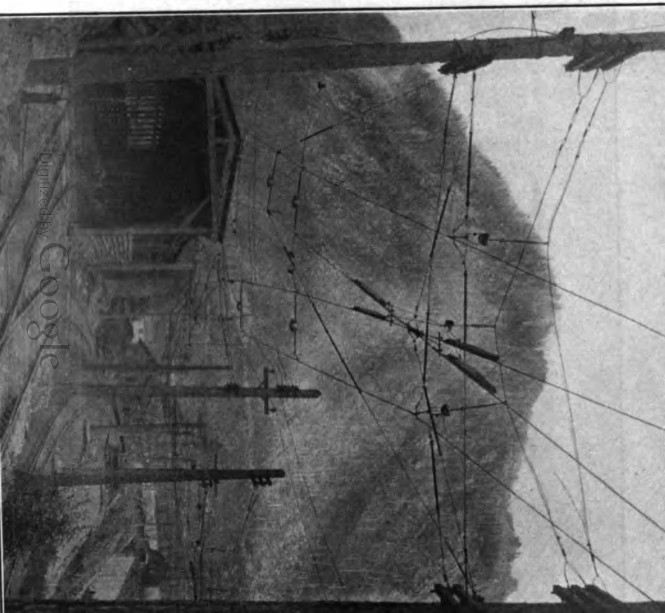


FIG. 14.—Anchor bridge in Wellington yard, showing three tracks electrified



14.—Anchor bridge in Wellington yard, showing three tracks electrified



whitewash the tunnel and light it electrically, and for this purpose a lighting system has been installed. Five transformers of 4 kw. capacity each are placed in refuge chambers; incandescent lights are spaced 50 ft. apart and are connected five in series of a 500-volt system. Several plans were worked out for this lighting system, but taking into account maintenance costs, it seemed best to use a standard 110-volt carbon filament lamp.

Telegraph lines. The telegraph wires, ten in number, as shown in Fig. 21 run through the tunnel in a cable; this service was thrown entirely out of commission when the electric locomotives began running. There is no interference with the telegraph wires due to the transmission lines paralleling them for thirty miles; the entire interference seems to originate in the tunnel. In order to eliminate this interference, a neutralizing transformer has been installed and adjustments are now in progress. There has been little difficulty in making the ordinary single-wire telegraph service satisfactory, but considerable difficulty has been experienced in

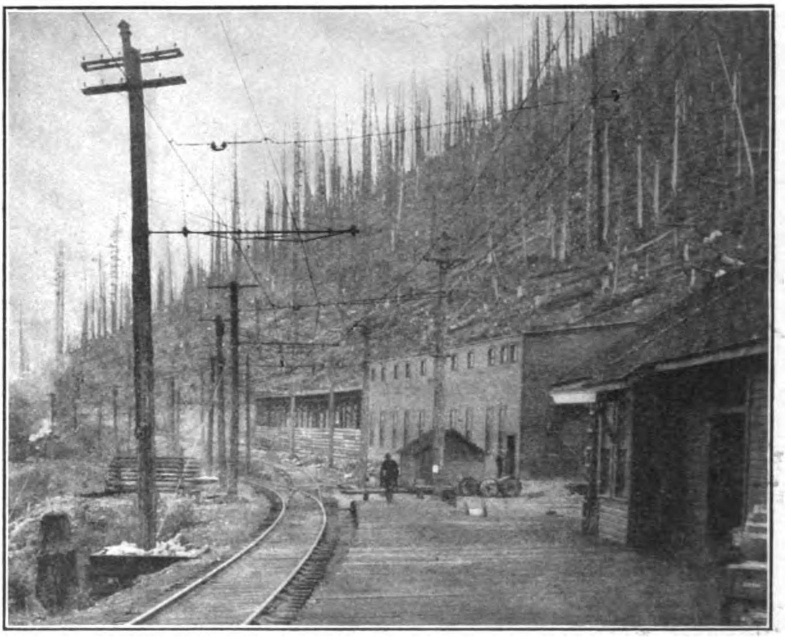


FIG. 16.—Bracket construction at curve Wellington yard

run through the tunnel in a cable,

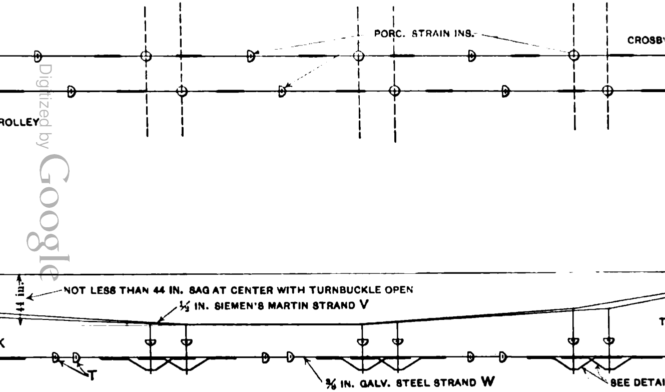

PORC. STRAIN INS.
CROSBY
ROLLEY
NOT LESS THAN 44 IN. SAG AT CENTER WITH TURNBUCKLE OPEN
44 in.
½ IN. SIEMEN'S MARTIN STRAND V
T
⅜ IN. GALV. STEEL STRAND W
SEE DETAI

Fig. C.

FIG. 17.—Cross-catenary suspension, general scheme]

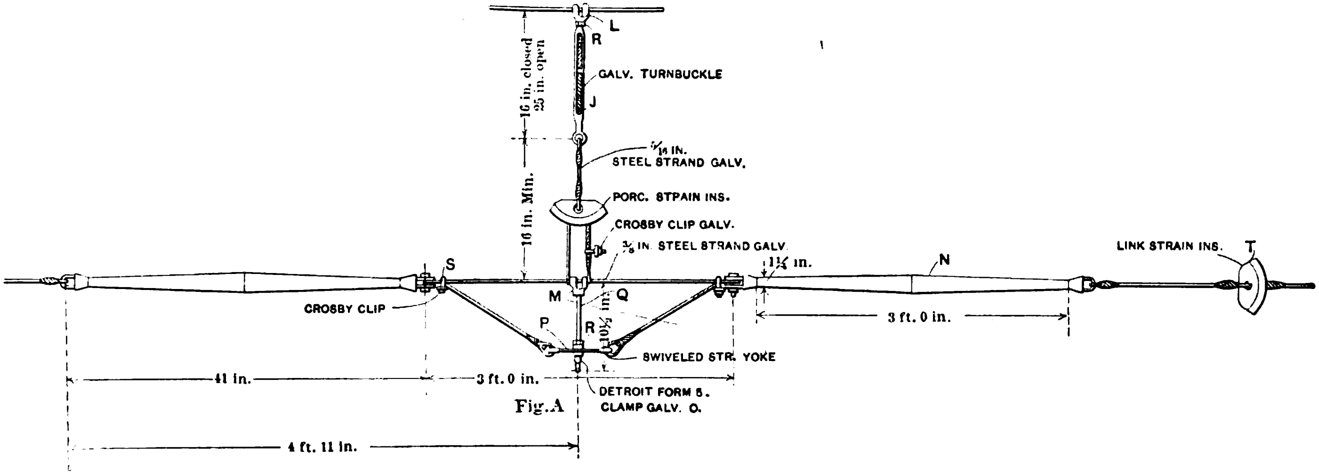
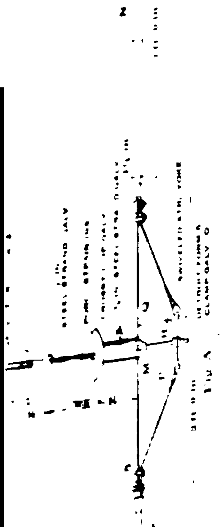


FIG. 18.—Detail *A* of Fig. 17 showing method of holding trolley wire.



Detail A of Fig. 17 showing method of holding trolley wire

ments of which 82 were freight, 98 passenger, and 32 spec In each case the steam locomotive was hauled through with train. The tonnage handled was as follows:

Freight tonnage	171,000 tons
Passenger "	88,500 "
Special "	15,500 "
Total	275,000 tons

This is an average of 8350 tons per day, all eastbound.
The average freight train weight has been as follows:

Cars	1480 tons
One Mallet locomotive	250 "
Three electric locomotives	345 "
Total train weight	2075 "

The maximum weight of cars was 1600 tons; the minim 1200 tons.

The representative passenger train handled is made up follows:

Coaches	426 tons
One steam locomotive	250 "

TABLE III

1 Test No.	2 Engine classification	3 Total weight with tender Tons	4 Weight on drivers Tons	5 Total resistance on 1.7 per cent grade lb.	6 Equivalent weight of freight cars Tons
1	Mallet No. 1904.2-6-6-2	250	158	19,340	482
2	" No. 1911.2-6-6-2	250	158	17,500	432
3	" No. 1905.2-6-6-2	250	158	24,200	602
4	Consolidation....2-8-0	159	90	10,080	255
5	Pacific..........4-6-0	188	70	10,270	257

The tests were made by towing an engine through the tunnel behind an electric; the electric was fitted up with test instruments and the total tractive effort was thereby obtained. An allowance of 6 lb. per ton was made for the resistance of the electric and the difference is the draw-bar pull in column 5. Column 6 is the equivalent load in cars, taking car resistance as 6 lb. per ton. Each test given is the average from six to twelve separate readings. The average for the three Mallets is more than 20,000 lb.

If the grade resistance be deducted from the total pull, and the difference lumped as "lb. per ton" for the locomotive and tender, there results:

TABLE IV

1 Engine classification	2 Frictional resistance of locomotive	3 lb. per ton
Mallet No. 1904.......	10,840 lb.	43.0
Mallet No. 1911........	9,000 "	36.0
Mallet No. 1905........	15,700 "	63.0
Consolidation..........	5,480 "	34.5
Pacific................	3,870 "	20.7
Electric...............	1,500 "	13.0

The average for the three Mallets is 47.0 lb. per ton for the frictional resistance on a straight level track.

The figure for the electric was obtained from tests made by

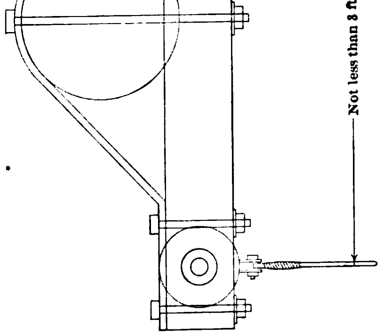
[illegible]	250	158	17,500	[illegible]
[illegible]	250	158	24,200	62
[illegible]	150	90	10,080	55
[illegible]	100	70	10,270	55

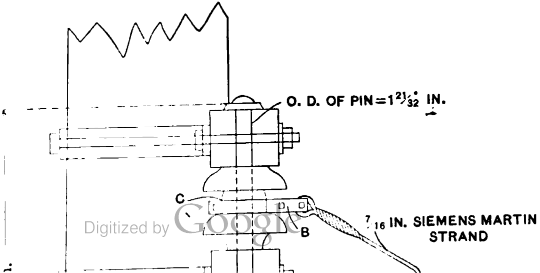
de by towing an engine through the [illegible] the electric was fitted up with test [illegible] tractive effort was thereby obtained [illegible] per ton was made for the resistance [illegible] is the draw-bar pull in column [illegible] load in cars, taking car resistance [illegible] test given is the average from six to [illegible] The average for the three Mallets is [illegible]

[illegible] stance be deducted from the total pull [illegible] as "lb. per ton" for the locomo[illegible] results

TABLE IV

2	3
Frictional resistance	lb. per ton





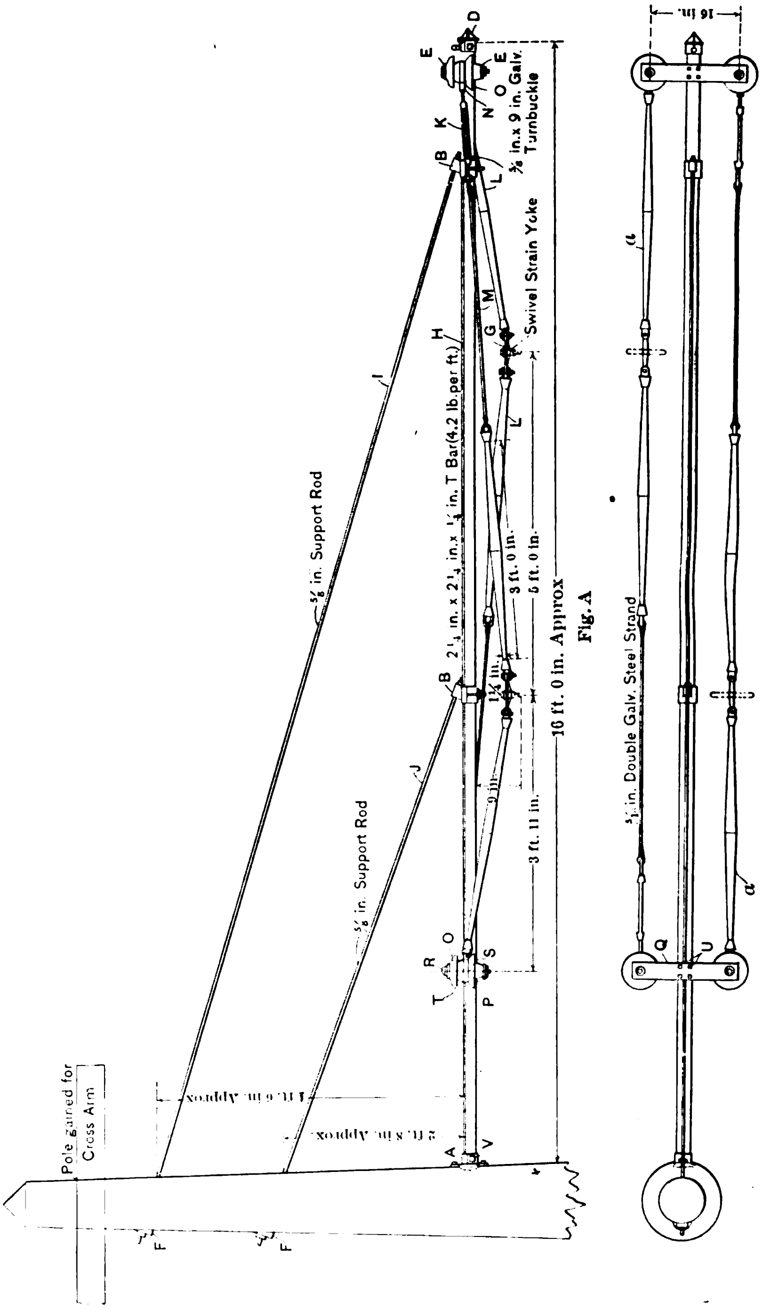
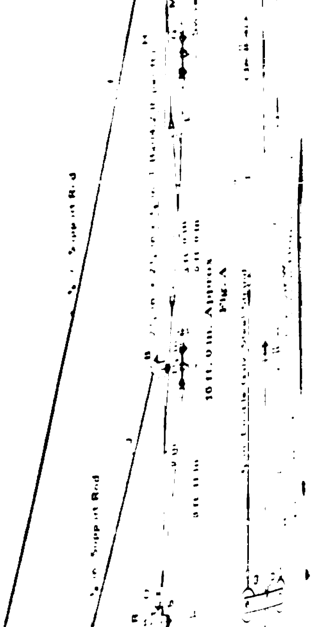
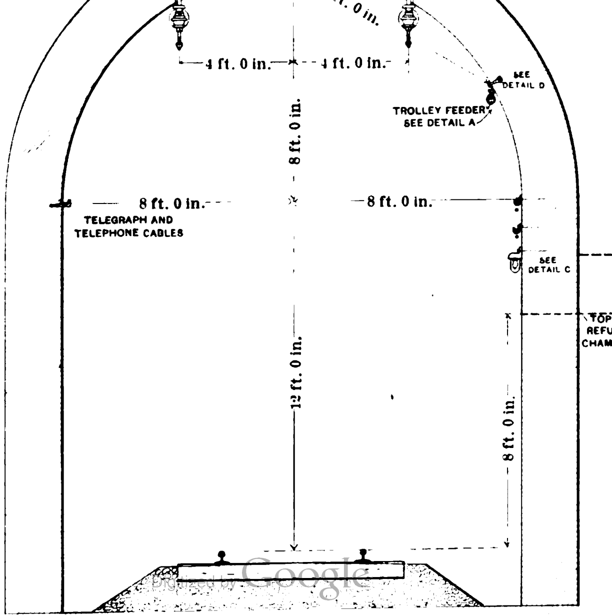


FIG. 20.—Bracket construction in yards


10 ft. 0 in. Approx.


0 in.
4 ft. 0 in.
4 ft. 0 in.
SEE DETAIL D
TROLLEY FEEDER
SEE DETAIL A
8 ft. 0 in.
8 ft. 0 in.
8 ft. 0 in.
TELEGRAPH AND TELEPHONE CABLES
SEE DETAIL C
TOP
REFU
CHAM
12 ft. 0 in.
8 ft. 0 in.

On account of the very high frictional resistance of the Mallet engine as a towing load, this representative train is equivalent to 1980 tons, excluding the three electric locomotives, or a total of 2325 tons, on the 1.7 per cent grade. This is on the assumption that the draw-bar pull required for the Mallet is replaced by freight cars at 6 lb. to the ton; this represents the average freight train handled.

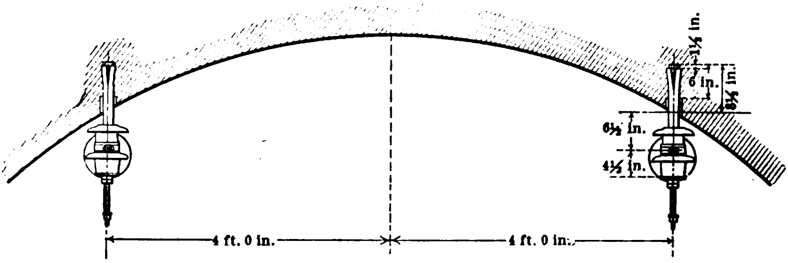


FIG. 22.—Cross-section showing trolley wires in tunnel

The tractive effort for the passenger trains varies from 40,000 to 50,000 lb., depending on the number of steam locomotives taken through; two electrics are ordinarily used, although one would answer in nearly all cases.

During this period there have been no delays due to failure of the electric locomotives, and but two trifling delays due to failures of the electric plant, both chargeable to the transmission line and both caused by accidents beyond the control of the operating force.

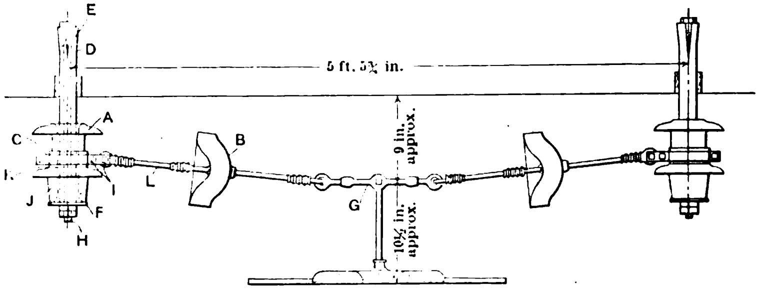
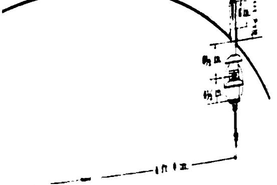


FIG. 23.—Longitudinal view of the tunnel suspension scheme—these supports are spaced 50 ft.

On August 11 the electric service was discontinued, owing to failure of both water wheels. Service was resumed on Sept. 9 and has been continued regularly since. The plant was taken



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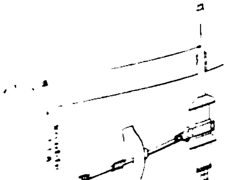
...there have been no delays due to failure
...motives, and but two trifling delays due to



TRAIN: MALLET ENGINE, 1550 TONS CAR WEIGHT, TWO ELECTRICS
1.7 PER CENT GRADE

Force due to grade		Frictional Resistance	Remainder for acceleration
Mallet	8,500 lb.	11,500 lb.	− 3,000 lb.
1550 tons in cars	52,500 "	9,300 "	+43,200 "
Three electrics	11,700 "	2,070 "	9,630 "
		Total for acceleration	49,830 "

This is equivalent to 1495 kw. delivered to the gears of t motors at 15 miles per hour.

The efficiency of the locomotive is approximately 80 p cent—hence the power returned to the line, should be 1200 k The test of this train gave 950 kw.; this difference is due to t standard practice, not yet abandoned, of keeping a certain nu ber of car pressure retainers set on down grade.

The Mallet, instead of adding to the delivered power is additional load that has to be carried by the train.

A similar test on a ten-car passenger train weighing 950 to gave

590 kw.

Place	Power Kilowatts	Per cent.
Power house low tension bus-bars	4740	100
Sub-station " " "	4250	89.8
Trolley wheel of the locomotive	4000	84.5
Driving axles " " "	3320	70.

The average efficiency is somewhat higher than 70 per cent.

HANDLING OF TRAINS

The maximum duty was imposed upon this equipment from the outset. On account of very poor regulation of water wheels, steam has been used in one of the Mallet engines in starting the freight trains in the Wellington yard; an attempt has been made to use just sufficient steam to enable the Mallet engine to turn itself over. Steam is shut off at the portal of the tunnel; in addition to this, in order to provide smoother starting, a slight air pressure has been maintained on the locomotive at starting, which is gradually reduced.

On several occasions trains have broken in two, due to the trolley wheel on the rear locomotive leaving the wire and thus cutting off part or all of the power supply to the rear locomotives. This throws a greatly increased draw-bar pull on the front locomotive, and the consequence is that the train is jerked apart. This happened in the early stages of the work, and was due to the fact that the turn-outs were not in the best order, and also that the engineers had not sufficient experience in handling trains. Another means taken to avoid the broken draw-bars was to use the rear Mallet engine to assist the train over the trolley crossings in the Wellington yard; this was a temporary measure and has been discontinued.

Economy of Mallets. It is interesting to compare the performance of a Mallet compound locomotive under the same operating conditions as this system. The data for this are given by Mr. Emerson, superintendent of locomotive power of the Great Northern Railway Company, in a discussion before the American Society of Mechanical Engineers on locomotives of this type;* as an excellent performance he gives these data:

> Recent performance shows that on a round trip over this division the L-1 engines handled 1600 tons with a total of 43$\frac{5}{8}$ tons of coal, or equivalent to 25.13 lb. of coal per 100 ton-mile.

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* Transactions of the American Society of Mechanical Engineers, Vol. 30, page 1031.

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crossings in the Wellington yard; this was a
been discontinued.
the perfor-

108.7 miles, is 1.3 kw-hr; the total work done in round trip
ton 5.56 kw-hr. There should be a negligible addition to
for starting the train.

The average train weight is:

Cars	1600 tons
One engine, 109 miles	
Second " 58 "	
Equivalent engine weight	380 "
Total	1980 tons

The coal used was 43$\frac{5}{8}$ tons, equal to 87,660 lb.

Coal per ton	44.3 lb.
Coal per killowatt-hour	8.0 lb

A modern steam station can deliver one kilowatt-hour for
of coal, at the bus-bar, which, with an efficiency of 70 per cen
the rail, gives a consumption of 4.28 lb. per kilowatt-hour at
rail; in other words, the Mallet compound requires nearly t
as much coal per kilowatt-hour at the rail as would be
in a modern steam station in the place of the hydroele
station at Leavenworth.

ADVANTAGES OF THREE-PHASE SYSTEM

shown by comparison with other electric locomotives; it is due to the fact that the losses can be kept lower in a three-phase motor than in any other type. As Fig. 3 shows, the electrical efficiency of the motor is high for a wide range of load.

3. *Uniform torque.* This is important, particularly at starting. I believe that a three-phase motor will work to a three or four per cent greater coefficient of adhesion than a single-phase motor at 15 cycles.

4. *The possibility of using* 25 *cycles.* This is important, as it leads to a less cost and a better performance of power station apparatus; moreover, it is standard and the power supply can readily be used for other purposes, as well as for traction; a commercial supply can be provided.

5. *Constant speed.* This is ordinarily stated as a disadvantage of the three-phase motor; but in my opinion it is a distinct advantage in mountain service, particularly the limitation of the speed on down grades. It has also the advantage on up grades that meeting points can be arranged with greater definiteness. There is a general notion that the impossibility of making up lost time with the three-phase motor will be a decided drawback to its use. This would be true if there were the same liability to lose time with three-phase motors; but when a train can be counted on to make a definite speed, without regard to conditions of tracks or of its load, there is less liability to lose time. Although I am not prepared to state that a three-phase motor is suitable for cases where the profile is very variable, yet it is by no means certain that it would not work out well; the question is merely one of making a given schedule between two points with greatest regularity.

6. *Regeneration on down grades.* This matter has been discussed since the earliest days of electric traction, but, as far as I know, has not been, up to the present, put into practice. Although this result can be attained with other forms of motors, yet it is most perfectly attained by three-phase motors, there being no complications involved. This is of importance in reducing the power-house capacity required for a given service; although, no doubt, the saving in power-house capacity will not be as great as indicated by theory, owing to the various emergencies that must be provided for, nevertheless there will be a material saving. A 2500-ton train on the average down grade of 1.5 per cent will deliver about 1400 kw. to the system. The equivalent power house capacity would cost at least

$200,000; hence if only 20 per cent of this can be utilized the saving will equal the cost of one locomotive.

7. *Excessive short-circuit current is impossible* and consequently destructive torque on the gears and driving rigging is eliminated. There will be no necessity for the complication of a friction connection between the armature and driving wheels, as in the design of recent large direct-current electric locomotives.

8. *Impossibility of excessive speeds.* Even when the wheel slips the speed remains constant. Therefore, the maximum stresses put on the motor are less and are more accurately known than with any other form of motor.

DISADVANTAGES OF THREE-PHASE

On the other hand, the principal disadvantages of three-phase motor, for traction use, are commonly stated to be:

1. *The constant speed.* This is rather an advantage for this class of service.

2. *Constant power.* The fact that the motor is a constant-power motor and therefore requires the same power at starting and while accelerating as at full speed. While this is true, it is not a matter of any particular consequence in a service where the stops are very few, and consequently the proportion of total time spent in acceleration is small, and where the additional power required to accelerate the train is a small percentage of the power used by the train at full speed. In this particular case on the 2.2 per cent grade, when accelerating at the rate of 10 lb. to the ton, the power required during acceleration is only 20 per cent greater than that required at full speed; this is not a serious matter.

3. *Small mechanical clearance.* In this particular motor the clearance is ⅛ in., which is ample for all practical purposes.

4. *Inequality of load on several motors of a locomotive due to differences in diameter of driving wheels.* To meet this an adjustable resistance is included in the rotor of each motor, the motors are then balanced up and no further attention is required as long as the wear on the driving wheels is approximately the same. If, at any time, the load becomes badly unbalanced it is a simple matter to readjust the resistances.

5. *Low power-factor of the system.* This does not seem to be borne out by practice. The power-factor, as shown by the switchboard instruments in the power house, is 85 per cent. This is a good result and is much higher than a power-factor

of a well known single-phase system that I recently had occasion to visit.

6. *Two overhead wires.* There is no doubt that two wires will cause more trouble than one, and in case of complicated yard structure it might not be practicable to use two overhead wires; but where the problem is that of a single track with an occasional turn-out or crossing there is, practically speaking, no more difficulty in maintaining two wires than one.

In brief, in service, of this character the three-phase motor has marked advantages in capacity, reliability, simplicity, and general trustworthiness, when compared with any other motor.

SOME MINOR ADVANTAGES OF ELECTRIC TRACTION

In the many discussions of electric traction which have recently taken place, I do not find several minor advantages sufficiently emphasized. One of these advantages lies in the fact that with electric traction the exact performance and condition of the locomotives and of all elements of the system is accurately known at each moment; on the other hand, with steam locomotives neither the engineer nor the motive power man can have any clear knowledge of the conditions of operation at the moment; he can only ascertain the performance of the locomotive by elaborate tests, which, as a matter of fact, are seldom made. The ratings and performance of steam locomotives are made up largely by " authority " based on a few tests from time to time, and take no cognizance of the actual condition of the locomotives. The importance of this, I think, is clearly brought out by the tests of the steam locomotive cited herein.

With electric locomotives the operation on a heavy grade becomes as simple as on the level; the engineers and train men feel much greater confidence in the electric locomotives and consequently the mountain division ceases to be a terror to them.

Electric traction will permit the use of very long tunnels, which are not now possible on account of difficulty of ventilation. There is no particular reasons why tunnels of ten or twelve miles should not be operated as easily as those of one mile.

The great increase possible in the speed of trains with electric traction and the consequent increase in the capacity of a single track will operate to postpone for a long time the necessity for double tracking. This double tracking on a mountain is a very expensive piece of business and this saving alone will, in some cases, more than offset the cost of electrical equipment.

A word in closing: the construction work in the tunnel and yards was carried out under great difficulties, owing to the necessity of not interfering with the regular service of the road. At times it was not possible to work in the tunnel for more than one hour a day, and for days at a time two or three hours was all that could be allowed, but in spite of this the work was carried out with very satisfactory speed, due particularly to the skill and ability of my assistants, R. Beeuwkes and W. S. Skinner, and the unstinted assistance of the engineering department of the road.

A paper presented at a joint meeting of the Seattle Section of the American Institute of Electrical Engineers and the Northwest Electric Light and Power Association, Seattle, Wash., September 8, 1909.

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(*Subject to final revision for the Transactions.*)

PROTECTION OF ELECTRICAL EQUIPMENT

BY P. M. LINCOLN

The subject that I wish to discuss in this paper is the protection of electrical apparatus and transmission lines from the danger of breakdown to which such apparatus is subjected by electrical surges. The most frequent and severe source of electrical surges is lightning. There are other causes, arising from the operation of a transmission line and the electrical apparatus that goes with it to make up a complete plant. For instance, switching, particularly on the high-tension side, may give rise to surges. Also grounding of high-tension transmission lines, particularly if the ground be an arcing one; for instance, such as would occur were the limb of a green tree to come occasionally in contact with one of the conductors of the line. Also a short-circuit on the transmission line or on other electrical apparatus may give rise to an electrical surge.

The question which I wish particularly to discuss in this paper is, therefore, the manner in which such surges may arise and the best protection to supply in order to prevent them from damaging either the apparatus or the service. I do not expect in this discussion to bring out anything new. The most that I could possibly expect is to bring a new viewpoint to some who are interested in long-distance power transmission and the protection of transmission circuits from damage and interruption.

What is meant by the term "surge"? This is a fair question and should have a straightforward answer. If this question were to be asked of a Steinmetz, he would fill pages with differential equations and $\int$ signs of integration and finally give an answer (as he has already done) in the form of a mathematical formula.

Such an answer, although it tells the story, is unfortunately useless to the average long-distance transmission line operator, since it requires the mind of a trained mathematician to interpret such an answer as well as to make it.

For my own part I have found that a proper conception of the phenomenon of electrical surges can be much better conveyed to the mind by using an analogy. The use of a proper analogy conveys a concrete idea rather than an abstract one, and the mind can much more readily grasp the idea in that shape than when it merely consists abstract ideas which must always be associated with such electrical terms as volts, ohms, henrys, microfarads, etc. Any analogy must be used carefully, since in many points of comparison it is apt to fail. If improperly used, it may lead to conclusions entirely wrong; but if properly applied it will lead the average mind to a much clearer conception of what is going on than can be obtained by any consideration of abstract quantities.

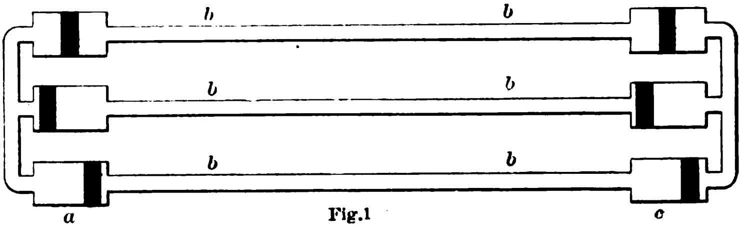

Fig.1

In many respects the following hydraulic analogy is similar to the electric circuit, and I trust that its description will be of assistance to some in gaining an idea of an electric surge. Suppose we replace a three-phase alternating-current generator, transmission line, and receiving apparatus with a hydraulic arrangement as shown in Fig. 1. In this Fig. *a* is the piston pump with the three pistons 120 degrees apart. *c* is a duplicate of pump *a*, whereby the work done by *a* is transferred to *c*. *b b b* are pipes connecting *a* with *c*. The likeness to an alternating-current power transmission system is accentuated in our analogy by the fact that the water or other liquid in the system simply oscillates through the pipes *b b b* from generator pump *a* to motor pump *c*. In order to endow this hydraulic system with the functions of an electric circuit we will have to imagine that the walls of pipes *b b b* are perfectly flexible; for instance, made of pure india rubber. This introduces into our hydraulic system the analogy of static capacity in the electric system. If we imagine that water is to be used in the hydraulic analogy, the weight or inertia of this water introduces into the hydraulic system the equivalent of inductance or reactance in the electric system. Since the water in passing back and forth will have certain losses due to friction against the walls of the pipe and pumps, the idea of ohmic resistance of the electric circuit is transferred to the hydraulic analogy.

If we wish to imagine the effect of increasing static capacity, we might do so in our hydraulic analogy by imagining the walls of the pipe to become more flexible; for instance, made of thinner walls of rubber. For a transmission line without capacity we would have to substitute a hydraulic system with perfectly rigid and inflexible pipes. Increasing inductance or reactance may be represented in our analogy by increasing the weight and therefore the inertia of the liquid pumped; for instance, by substituting mercury for water. Increasing electric resistance may be represented by smaller, rougher, or longer pipes, thus increasing the frictional resistance. It is further necessary to assume that the volume of the pump cylinders is large compared with the volume of the pipes connecting the two pumps; and to gain a proper idea we would have to imagine further that the speed of the pumps is slow, say one stroke per minute or so.

Now if we can keep our imaginations under proper control and can carry this hydraulic analogy in our minds we are prepared to investigate the nature of an electric surge by means of this analogy. Suppose we suddenly inject into one of the flexible pipes *b b b* at some point between pumps *a* and *c*, an amount of liquid which will instantly swell the pipe at that point to some three or four times its normal diameter for a length of some eight or ten diameters. This would be analogous in the electric system to the effect of lightning. A cloud discharges in the neighborhood of a high-tension transmission line. The area of the transmission line which has been covered by the cloud is relatively small. The discharge of that cloud releases in the transmission line a certain amount of static electricity in addition to the normal amount of current present due to the action of the generators and receiving apparatus. What happens next? It is much easier for the imagination to follow this in the analogy than in the actual transmission line. If the pipe is not strong enough the wall breaks; that is, an insulator punctures or "slops over," and the accumulation of water, [electricity] in part at least, escapes. If the walls of the pipe are strong enough to stand the strain; that is, if the insulators do not break down, a wave or surge begins to be propagated in both directions. The distended walls of the pipe bring their elastic force to bear upon the enclosed liquid and the accumulated "lump" of water begins to de dissipated in both directions. Inertia of the liquid together with the pressure on it from the elastic walls will cause it to assume successive forms which are probably very much like those shown in Fig. 2. The accumulation of liquid will become longer and thinner, and it finally divides into two separate lumps as it travels from the point of disturbance in both directions. At the point of disturbance the tendency to break the walls is a maximum, and this tendency becomes less and less as the wave or surge proceeds from the point of disturbance. However, should the surge encounter a weak place in the walls, a break may occur in some place comparatively remote from the point of disturbance.

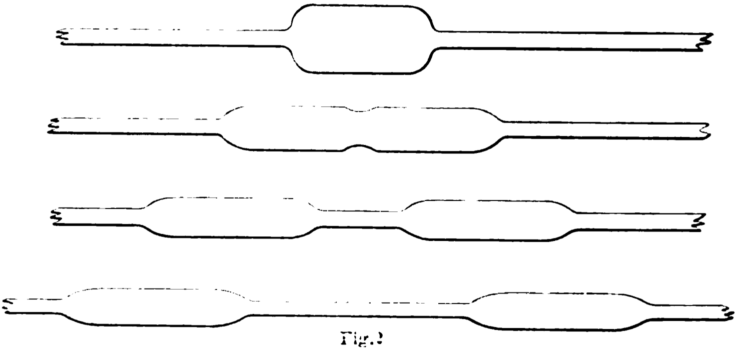

Fig.2

Now, what happens when this wave or surge reaches the electrical apparatus at the ends of the line? For the purpose of considering this question, we should have to replace our pumps with something that would behave like a transformer or generator in an electric system. Now generator and transformer windings have two important differences from an equal length of transmission line, in that both the capacity and inductance per unit length are largely increased. In our hydraulic analogy the increase in capacity per unit length may be represented by imagining a much thinner walled pipe for the generator. The increase in inductance per unit length may be represented in the analogy by an increase in the specific gravity of the liquid, say by substituting mercury for water. I have endeavored to give a graphic representation of these modifications in Fig. 3.

b_1 is the transmission line with relatively heavy walls, although still flexible, and a light liquid contained therein, say water.

b_2 is the generator which has relatively thin but still perfectly elastic walls containing a heavy liquid, say mercury.

When the wave or surge that has been started out on the line b_1 reaches the point p; that is, the terminal of the generator or transformer, it is obvious that the following things will occur:

1. A part of the energy of the incoming wave will be reflected and will therefore travel back through the line b_1 from the point p.
2. The remainder will begin to travel through part b_2, the generator or transformer; but the speed of its propagation will be very much reduced, because the liquid being set in motion is very much heavier and also because the forces acting upon it through the elastic retaining walls are much smaller.

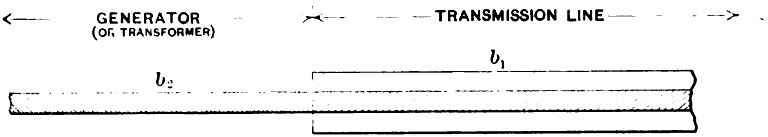

Fig.3

3. The steepness of the wave-front during its propagation through b_2 will be very much increased over that obtaining in b_1, on account of the action of the same forces as noted in the above paragraph.

I have allowed my own imagination rather free play, and give in Fig. 4, 5, 6 and 7 my idea of how the wave will modify itself when being propagated from medium b_1 to medium b_2. Probably the most noteworthy modifications during this transfer of the disturbance from b_1 to b_2 is the abrupt increase in the steepness of the wave-front. For instance, consider the points p_1 and p_2 in Fig. 5. At p_1 there is a tendency to burst the pipe; that is, to breakdown the insulation to ground; but there is also a heavy stress tending to break through from point p_1 to point p_2. Suppose that the portion b_2 of our pipe, instead of being straight as indicated in the diagram were to be coiled upon itself, and that one complete coil took place in the distance from p_1 to p_2, then there would be a tendency for the liquid at point p_1 to break through the walls of the pipe into the neighboring coil at p_2. This is exactly what occurs in the electric system. An incoming surge, in penetrating the turns of electrical apparatus, causes an excessive voltage strain between adjacent turns. The momentary breakdown or snapping across of this surge from one turn to the next will do no particular damage unless such breakdown is followed by the dynamo current and an arc is thereby established. If this later event occurs then the break does tre-

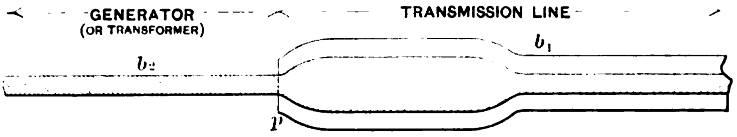

Fig.4

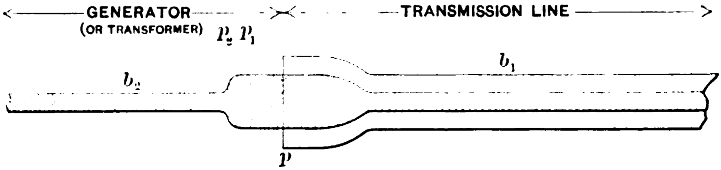

Fig.5

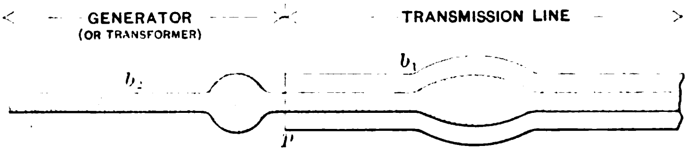

Fig.6

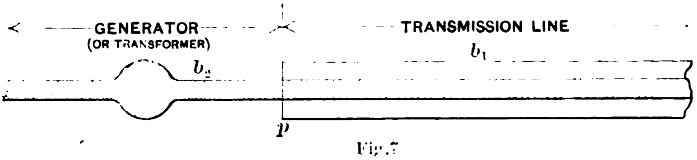

Fig.7

mendous damage. In my opinion, practically all of the failures in generators, transformers, etc. which can be traced directly to lightning or other surges are due to a breakdown between turns rather than to a break in the insulation from conductor to the ground. There is, of course, due to the normal operation of the apparatus, an insulation strain from conductor to ground and also one between adjacent turns. A surge momentarily increases both of these strains. The strain to ground may be thereby increased 20 per cent, 50 per cent, or perhaps 100 per cent, or even somewhat more; the strain between turns may thereby be increased twenty times, fifty times, one hundred times or even more. A surge, therefore, throws a much larger increase on the insulation between turns than it does on the insulation to ground. From certain observations that I have made, it is my opinion that the momentary strains between turns, particularly near the terminals of the apparatus, may approximate a considerable percentage of the terminal pressure. This is a danger in electrical apparatus which has not been sufficiently appreciated in the past.

It is evident that the protection of electrical apparatus from such dangers as are outlined in the above consists in:

1. Making the apparatus so that it will stand large momentary voltages between turns. This consideration shows the great advantage possessed by transformers, particularly oil-insulated, over generators. It is possible to insulate transformers between turns to a much higher degree than any generator can be, particularly where oil is used.

2. Limiting by use of proper lightning arresters the size of the wave or surge that may enter the electrical apparatus. Reverting to the hydraulic analogy, if we should provide a hydraulic relief valve at the point p, Fig. 5, it would have the effect of removing at least a part of the excess liquid at the instant the strong pressure on the walls occurs. If this relief valve were to be set so that it operates at a pressure of, say, only 20 to 30 per cent above that caused by the pumps while in normal operation, then this relief valve would not affect the normal operation and would also limit a surge or wave entering part b_2 to an amount which could not exceed 20 or 30 per cent above normal pressure or voltage. This indicates the function of the ideal lightning arrester. It prevents any electrical surge which has a value of 20 to 30 per cent greater than normal voltage from entering the electrical apparatus. This is the utmost that any lightning

arrester can do. The electrical apparatus itself must be so designed that it will take care of an entering surge which is not more than 20 or 30 per cent above line voltage.

Reverting again to the hydraulic analogy, suppose our relief valve has a relatively long discharge pipe, say one-one-hundredth the area of the incoming pipe b in Fig. 1. The time during which the excess pressure exists at p, Fig. 5, is relatively small. Such a pipe attached to the relief valve would be utterly unable to discharge a sufficient amount of the liquid to relieve the pressure. As a consequence, the size of the surge entering part b_2 would be but little reduced by such a relief valve. This is analogous to what occurs with a lightning arrester having a large ohmic resistance in series with it for the purpose of preventing the dynamo current from following. This indicates in general why this type of arrester is inferior to the electrolytic. The electrolytic type of arrester, once broken down, has almost a zero resistance to ground and therefore allows the maximum possible reduction of the surge before it enters the electrical apparatus.

Another method of protection that has shown itself of considerable value both in theory and practice (as a protection from lightning) is the overhead grounded guard-wire. The theory of this kind of protection is as follows:

Any conductor that is entirely enclosed or surrounded by another conductor cannot have induced thereon a static charge which originates from any action going on outside the surrounding conductor. For instance, a lead-covered electric cable cannot be directly subjected to lightning disturbances because of the protective action of the surrounding lead sheathing. The overhead ground-wire acts to a certain extent in the same manner. Although it does not entirely surround or enclose the high-tension wires which it protects, it does so partly and to the extent that it does enclose or surround the high-tension wires it provides the same protection as does the lead sheath to the underground cable. In the electric transmission circuit the voltage of the charge which would otherwise be induced upon the transmission line is kept down by the presence of the guard wires.

Still another method of protecting high tension-transmission line is to ground the neutral of the lines. This grounding may be done either by connecting it solidly to the ground or by putting in a greater or less resistance between the neutral point and the ground. To just what extent this grounding of the neutral either completely or partly is of value is a moot question among engineers. As I see it, the question of grounded neutral versus ungrounded may be considered from two view points: first, from the viewpoint of protection of the apparatus or equipment; secondly, from that of the protection of the service.

First: protection to apparatus. The advantage in a solidly grounded neutral, so far as protection to apparatus is concerned is that the normal voltage to ground can under no conditions rise to more than about 58 per cent of the normal voltage between conductors. This advantage is, of course, of the utmost importance when considering insulation strengths to ground of the various apparatus involved.

On the other hand, the disadvantage of a solidly grounded neutral is that every ground which occurs develops immediately into a short-circuit, and these short-circuits in turn cause severe mechanical stresses to be set up in the windings of the transformers and the generating apparatus.

With a grounded neutral, therefore, it is reasonable to expect that the windings of the transformers and generators will be subjected to much more frequent shocks than without such a ground. Also owing to the fact that every ground immediately becomes a short-circuit, and that at points of short-circuit the arc will cause considerable destruction, the system with the solidly grounded neutral will be subject to more frequent destructive arcs both on the line and in the apparatus where there is probability of such arcs developing.

It is my opinion that so fas as protection to apparatus is concerned, the advantages of grounding the neutral very much outweigh the disadvantages; and if protection to apparatus alone were to be considered, I would have no hesitation in recommending for a solidly grounded neutral.

Secondly, protection to the service. As mentioned above, the disadvantage of a solidly grounded neutral is that every ground develops immediately into a short-circuit. With a voltage such as is always used in high-tension transmission, (say 44,000 and above) there will always be a sufficient voltage at the point of arc to cause that arc to continue until the power to that particular section of line is cut off. This fact almost invariably will cause an interruption of power whenever a ground occurs on any point on the transmission system.

This would not be so materially a disadvantage were it not for the fact that experience has again and again demonstrated that lightning storms will very often cause insulators on the line to arc across or puncture. With the neutral solidly connected to ground, each one of these punctures and flash-overs means an interruption of service. If the line were not solidly grounded, it is probable that many of these flash-overs would not interrupt the service, since a flash-over involving only one conductor might simply mean that the other two conductors on the transmission line would momentarily rise to a potential nearly double normal while the arc at the defective insulator, as well as the voltage to maintain the arc, disappears.

In view of the difficulties which the line is apt to encounter with a solidly grounded neutral, many engineers prefer to ground through a resistance instead of connecting the neutral solidly to ground. In order to be of use, the resistance between the neutral and ground must be relatively high, and further it must be able to carry a considerable current for at least a short period of time. In other words, it must be capable of dissipating a very considerable amount of energy for a short period. A satisfactory type of resistance for this grounding service is difficult to obtain. Cement columns have been used, but these are unsatisfactory owing to the extreme variability of their resistance. Also if the current through them is maintained for an appreciable time, the heat developed is apt to crack or even to burst them. After studying the question from various angles, I have come to the opinion that a metallic form of resistance is the proper one to use for this purpose. The main disadvantage of this form is its cost, but its advantages are sufficiently great to overcome this disadvantage.

To recapitulate briefly: the protection against surges of electrical equipments, including both the apparatus and transmission lines, may be furthered by adopting some or all of the following methods.

1. *The overhead guard-wire.* This has the ability of keeping down the quantity of electricity which a given lightning discharge is capable of superposing upon a transmission line. In practice it has shown itself to be a valuable device in many instances of high-tension transmission.

2. *The use of efficient lightning arresters is essential.* They should be of a type which will allow a free discharge of static electricity from the transmission line whenever the voltage of the charge exceeds normal by a certain predeterminable amount.

With a proper equipment of such lightning arresters, the size of the surge which may enter electrical apparatus is limited.

3. *The grounded neutral.* Grounding solidly prevents the potential of a neutral point of a transmission line from departing from ground potential. This in turn will prevent the normal operation of this line from causing more than about 58 per cent of line voltage appearing between any conductor and ground. Grounding through a resistance has the same effect, to an extent depending upon the amount of resistance used.

4. *Insulation between turns.* The analysis in the preceding discussion shows that it is highly essential to insulate electrical apparatus between turns so that it will stand a momentary potential which is many times that normally put upon the insulation. The consideration of this point shows at once the enormous advantage of using transformers upon a transmission line in distinction to connecting generators direct. The amount of insulation that can be used between turns in a generator is limited by the necessity of placing the winding in relatively small slots. In a transformer this consideration does not operate to nearly so great a degree, owing to the fact that the space occupied by the windings is, so to speak, in one piece instead of being divided up into a large multiplicity of small slots. Also the presence of oil in the case of the transformer gives it an advantage which the generator cannot have under any conditions.

DISCUSSION ON "OUTPUT AND REGULATION IN LONG-DISTANCE LINES," AND "CALCULATION OF THE HIGH-TENSION LINE." FRONTENAC, N. Y., JUNE 29, 1909

(Subject to final revision for the Transactions.)

T. R. Rosebrugh (by letter): Mr. Thomas refers to the time required to work out formulas given by previous writers. The time occupied in making a calculation, however, consists of two parts: first, the verification of the formulas to be used, by a critical examination, for they may contain typographical errors, or be misunderstood; secondly, the actual computation. The longer and more unsymmetrical a formula is the more time one would in general take in checking it.

The following are simple, convenient, and flexible, yet give the general solution for the steady state:

$$E_1 = E_0 + z\,I_0 + \tfrac{1}{2}\,z\,y\,E_0 + \tfrac{1}{6}\,z^2\,y\,I_0 +$$

$$I_1 = I_0 + y\,E_0 + \tfrac{1}{2}\,y\,z\,I_0 + \tfrac{1}{6}\,y^2\,z\,E_0 +$$

two series converging in all practical cases quite rapidly, in which each symbol denotes a complex quantity according to Dr. Steinmetz' notation, E_0 and I_0 being for the receiving end E_1 and I_1 for the transmitting, and z and y are the quantities $r + x\,j$ and $g + b\,j$, respectively, for the whole line.

Whether it has occurred to anyone to publish this form of the solution I do not know, but they seem not to be so well known as they deserve.

In addition to these equations, those obtained by using a minus sign before each even numbered term may be employed in preference when the known end of the line (E_0, I_0) is transmitting power instead; this makes the power component of I_0 in both cases positive when E_0 is denoted by a positive real quantity.

Suppose in the first place that one condition only of the line is to be calculated, the least labor will then be expended by proceeding as follows:

Starting with I_0 (complex quantity) multiply it by z and this again by $y/2$. Similarly starting with E_0, multiply by y, and this product by $z/2$.

On looking at the two series it will be seen that following two zigzag lines the first three terms of voltage and current are now known, and simple addition will now usually determine both components of each with sufficient accuracy.

If the line be so long that the last term calculated above in either series is not small enough, proceed further along either or both zigzags until satisfied. It will be noticed that the successive factors for one zigzag are $\frac{z}{1}$, $\frac{y}{2}$, $\frac{z}{3}$, $\frac{y}{4}$, etc. and $\frac{y}{1}$, $\frac{z}{2}$, $\frac{y}{3}$, $\frac{z}{4}$ for the other.

Thus no labor is wasted, each multiplication giving one term, and the error is known to be much less than the last term calculated in the given series.

Secondly, if the calculation is to be made for several different conditions (which may be given for either end) it is easiest to find first the coefficients of E_0 and I_0 in the two series, and these are readily found numerically also, three multiplications only serving to determine what is required to the end of the fourth term in both series. In this simple manner A, B, C are found such that

$$E_1 = A\,E_0 + B\,I_0$$

$$I_1 = A\,I_0 + C\,E_0$$

hold for given conditions at receiving end and

$$E_1 = A\,E_0 - B\,I_0$$

$$I_1 = A\,I_0 - C\,E_0$$

for given power house conditions. These forms of the series are now conveniently ready to deal with any values of E_0 and I_0 which may be inserted.

To prove that the first series given are correct it is only necessary to remember that a Taylor's expansion requires merely the successive derivatives of the variable at one given point. Now since $\frac{dE}{ds} = z\,I$ and $\frac{dI}{ds} = y\,E$ everywhere on the line, (s being the distance from 0 in terms of the line as unit of length), these successive derivatives may be written down by inspection, and their values at the zero end are seen to be such that multiplication by $\frac{1}{2}$, $\frac{1}{6}$, $\frac{1}{24}$, etc. produce the terms of each series as stated, at the other end of the line where $s = 1$.

Intermediate conditions on the line may be found by retaining the proper powers of s. The two methods of calculation which take account of capacity, either all at the middle or divided equally between the ends, amount to taking three terms both of voltage and current, the former, however, includes also 3/2 of the fourth term of voltage, the latter also 3/2 of the fourth term of current.

Mr. Thomas' paper contains a recommendation to calculate three-phase transmissions by reference to a single-phase circuit in which all the quantities concerned are different from those of the actual three-phase circuit or its parts.

Would it not be better to calculate the actual circuit as a star arrangement; that is, each of the three wires with its own actual resistance, reactance, capacity to neutral, and leakage conductance as the line portion of a circuit carrying its share, namely one third of the power and at the star voltage?

It may perhaps be said that the recommendation is harmless, but the result of such propositions is apt to be, as has already occurred, that tables are prepared giving fictitious quantities for three-phase lines instead of the real ones. This leads to a state of affairs in which handbooks become unsafe to use, for such tables are apt to be given without adequate warning as to the special fiction they favor.

The paper deals with three distributed line constants but omits the fourth—leakage conductance. This may be taken into account and his formulas thus given greater generality as follows. Let r, x, g and b have their usual value as real numerics, and in this case z and y also the real values $\sqrt{r^2+x^2}$, $\sqrt{g^2+b^2}$ instead of complex quantities as above, and all six for the whole line.

For	Write
$\alpha x = \frac{Rx}{2}\sqrt{\frac{2pC}{pL+\sqrt{R^2+p^2L^2}}}$	$\sqrt{\frac{zy+rg-bx}{2}}$
$\frac{px}{v} = x\sqrt{\frac{pC\,(pL+\sqrt{R^2+p^2L^2})}{2}}$	$\sqrt{\frac{zy-rg+bx}{2}}$
$\sqrt{\frac{\sqrt{R^2+p^2L^2}}{pC}}$	$\sqrt{\frac{z}{y}}$
$\frac{p}{\alpha v} = \frac{pL+\sqrt{R^2+p^2L^2}}{R}$	$\sqrt{\frac{zy+rg+bx}{zy-rg-bx}}$

One might gather from the reference to the perfectly uncharged line that the scope of the paper is sufficient to deal with transient states of the system; this, however, is elsewhere stated not to be the case.

The statement that the current produces a drop in the line proportional to the current and the square root of the impedance and inversely proportional to the square root of the capacity susceptance seems inadequate and misleading, for the factor omitted is also a function of the line constants for both terms involving the current.

In the investigation of the so-called split conductor the currents in the strands are taken to be different as indicated by the factor k, but there appears to be no reason given for neglecting the slight phase difference one would naturally expect between the currents a_2 and a_3, due to the revolving field in which they are situated.

However this may be, if the three strands are transposed so that each has an equal length in each position, then k becomes zero, and this phase difference vanishes also.

Checking by a different method the final result for L, and on the assumption that the strands are given a cyclical transposition, I obtain the same expression on the understanding that t is small in comparison with D.

It would then be a question whether for slight separation of the strands (if the construction should be adopted) the extra losses would be sufficient to justify the expense of the slight insulation necessary with transposition to avoid them.

V. Karapetoff: I think the first paper contains a good deal of what could be called prophetic vision. At the present stage of the development of exceedingly long transmission lines such prophetic pictures are as important to us as detailed investigations of the performance of such lines. It is necessary for us, and particularly for our leaders of industry, to have such clear mental pictures, before we can see these transmission lines realized in practice.

I would suggest that Professor McMahon's book of hyperbolic functions is a good book for engineers who wish to use hyperbolic functions in addition to plain trigonometry. It is a book which is easily readable, and what makes it particularly valuable to electrical engineers is the fact that the same problem on transmission line which is solved in Dr. Kennelly's article, in the 1895 TRANSACTIONS of the Institute, is worked out and considerably simplified in this book. In place of Dr. Kennelly's charts, Professor McMahon has calculated more accurate tables of hyperbolic functions of complex quantities, with double entry, so that the calculations are easily performed.

However, I think that all the possible mathematical methods should be open for the use of engineers. Some of us may prefer hyperbolic functions, others may prefer Dr. Steinmetz's method. Others again may prefer the treatment within the limits of plain trigonometry, as given in Mr. Thomas' paper. I do not think that we should limit ourselves to any specific method, because the temperaments and natural inclinations of engineers differ very materially. This may be likened to the case of two mechanics building similar devices. One would spend most of his time in making special tools with which to construct the device; the other would prefer not to make special tools, but to devote all the available time to building the device itself.

But even granting that Mr. Thomas's method of treatment is legitimate and useful, I do not believe that he did full justice to the method: the deductions can be considerably simplified. The paper will undoubtedly be referred to by many of us later on. Therefore, I would suggest that Mr. Thomas, give the paper to some professional mathematician and ask him to go over it and simplify the equations.

John B. Taylor: In transmitting power with direct current, we are all familiar with the fact that the only limitation as to distance is the size and price of copper conductors. With alternating-current work we find other limitations. After obtaining the right of way and paying, say, a million dollars for this with steel towers, insulators, etc., then we find that we can effectively put up only a certain size of copper wire. This is because the reactance of the circuit is reduced practically not at all as the wire is increased in size, and the reactance may be the limiting factor in the amount of power to be got over the line. Of course the reactance can be reduced to a certain extent, either by bringing the wires closer together, or by putting up a multiple circuit. The multiple circuit in its most efficient form means a distinct pole line, with perhaps another million dollars for duplicating right of way, steel towers, etc. Reduction of inductance by splitting the conductor, as suggested in the paper, may be effective; but this involves more dollars, and special construction of insulators and supports which have not been tried out.

The paper disappoints me from the fact that after reading it I find myself with no clearer physical conception of the interactions and reactions of distributed resistance, inductance, and capacity in the transmission line. This I think is due to the use of the term "energy" for something which is not energy, and the lack of any fixed direction of energy transfer as a reference, which allows Mr. Thomas to call the same current leading or lagging according to which way he looks at it. Receiving apparatus is also spoken of as *supplying* current and energy. This special use of terms and shifting point of view makes it difficult to follow the exposition. I hoped that Mr. Thomas would give a clear mental picture of the changing values and phases of current and potential at numerous points of the long-distance, alternating-current line, which from one point of view is merely an indefinite number of condensers, reactances, and resistances connected together. If we can solve the more familiar case of reactive coil, tin-foil condenser, and resistance box on alternating current, by extension we should understand the long-distance transmission line. Determination of actual values may involve mathematics too difficult for many of us, but a rational understanding of what we are dealing with seems desirable before passing to the long equations.

Charles P. Steinmetz: I consider the extensive use of the terms leading and lagging power as one of the most valuable features in this important paper. For a number of years I have been trying to introduce these terms instead of the frequently employed terms "lagging current" and "leading current." Lagging power and leading power, or combined in one expression, *reactive power*, is a real, existing quantity, but not so reactive current, as lagging or leading current. There is no such thing as lagging current, absolutely; it is only relative. Referring to an induction motor under a given condition of operation, it may be said that the motor takes so many volt-amperes reactive power, but it cannot be said that it takes so many amperes reactive current for magnetization. Magnetizing current is wattless or reactive only with reference to the induced electromotove force, but it is very far from wattless with regard to the impressed electromotive force. Hence, applied to current and voltage, " reactive ", " leading ", and " lagging " are relative terms. This is particularly true in the case of a transmission line. For instance, in a 700-mile transmission line operating at 60-cycles, if the current and voltage are in phase at the generator, then at the receiving end the current will be approximately 90 degrees out of phase with the generator voltage; that is, the current from the line would be wattless in regard to the generator voltage. But it is not, obviously, wattless or reactive power; it is practically in phase with its own voltage at that place, the receiving end of the line; it merely means that the entire power has shifted 90 degrees, or, in other words, that the storage capacity of the line is sufficient to store the entire energy, and then send it out again at the receiving end, producing 90 degrees phase displacement. This feature makes the use of lagging current and leading current misleading and unsatisfactory in dealing with complex circuits.

Mr. Thomas' paper concludes that it is necessary, for economical transmission, to balance the leading and lagging energies of the line, and that balancing is done by adjusting the relations of voltage and current to the relations of inductance and capacity, so that the value of volts over amperes must be equal to the square root of inductance over capacity. This relation has a very simple physical meaning, which we must realize. It is the condition of free flow of electric power, the relation which exists for electric power in the transmission line as a circuit, which adjusts itself to change of conditions. For instance, if the electrostatic charge impressed upon the line by a lightning stroke readjusts itself by dissipation, or if the line discharges to ground, or an impulse or wave travels along the line, or if a sudden oscillation makes the line surge—in all these cases voltage and current are related as the square root of inductance and capacity. It will be seen, therefore, that the condition of maximum economy of power transmission is the relation of free flow of power.

It means, however, that for economic transmission, and more particularly for voltage regulation, we must have in these very long lines such methods of controlling the power-factor and the voltage at the receiving end that, at the economical load, the receiving circuit shall be non-inductive, and at light load the leading power of the line shall be supplied from the receiving circuit; that is, the receiving circuit feed leading current into the line, or, as it is usually expressed, the line sends lagging current into the receiving circuit. This necessitates a method of adjusting the power-factor by varying the phase relation of the load, so as to have the phase relation of the load change from lagging at light load, over non-inductive condition at the economical load, to leading at overload; in short, the well known method of phase control is required to get maximum efficiency of transmission.

In long-distance transmission lines, as a general thing, this is not yet done to any extent, but it is common practice in those long-distance transmissions in which the receiving apparatus is specially suited for the automatic variation of phase relation; that is, in railway systems with converter sub-stations. There this method of phase control of the line is generally used as it gives the best regulation and best economy.

As a corollary, therefore, in conclusion 7, the non-synchronous machine, or, as commonly called, the induction generator, is referred to. This is a type of machine especially adapted to a load in which the synchronous apparatus controls the phase relation with the load. The induction generator naturally adapts itself to the synchronous phase controlling receiver.

As regards the computing formulas, there are a number of formulas that give fair approximations. One of the simplest is the following: first consider the entire line capacity as a condenser at the generator; this gives a simple, quick computation. Then consider the entire line capacity as a single condenser at the receiving end; this is also a simple and quick computation. By averaging these two approximations we come close to the actual condition. These combined computations are far simpler than a single computation with the condenser at the middle of the line; at the same time they give a closer approximation. To find out whether they are really close enough, the complete calculation should be made for a few points. However, these calculations may be checked by estimating the capacity (the charging current of the line) as a percentage of the full-load current. So long as the charging current is less than a certain percentage, perhaps 20 or 30 per cent of the full-load current of the line, these localized computations are fairly satisfactory. Beyond that the complete line equations must be used, as stated by Mr. Thomas.

These complete equations are not so formidable as they look at first sight, but can be modified to very simple expressions. The disadvantage of the general equations for computation is the existence of the exponential function, which must be evaluated. Some months ago Mr. E. J. Berg and I had occasion to look into the question of calculating long power transmission lines quickly, so as to get within a half-day complete curves for different loads and different power-factors of the load. We found that for practically any commercial line, up to 300 or 400 miles, or even more, almost a perfect approximation could be got by using the complete equation, but substituting for the exponential functions the first terms of their series, which eliminates the stumbling blocks of the computation. The simple equations resulting thereform will be found later in this discussion.

Paul M. Lincoln: The practical engineer approaches these two papers with an interrogation something like this—what is there in them that can be of assistance to the electrical engineer who is about to design a long-distance, power transmission line?

The answer to that question, as I see it, is that for present conditions, and for those which will arise in the immediate future, as far as we can foretell them, there is little or nothing contained therein that will be of assistance to him. But for conditions which are apt to arise in the distant future the discussion and the analysis made in papers may be of considerable value. Mr. Thomas has made a close and careful study of the conditions which will obtain when a transmission line contains a certain type of resonance. This resonance depends upon at least three conditions, all of which must be satisfied before resonance can obtain: first, there must be a given load transmitted over the line; secondly, that load must be at a given power-factor; thirdly, there must be a given voltage. These three conditions, at least, must be satisfied before the particular type of resonance which Mr. Thomas has discussed may obtain.

For conditions below full load there is not sufficient current to cause an excessive drop; for conditions above full load the drop will increase very rapidly as the load increases. This increase will be so rapid as to place a practical limit to the line capacity at its full load. Hence we will have a line whose most economical point is at load *a*; it cannot carry more than load *a*, for less of a load its regulation will not be so good as for load *a*. Such a condition must, to say the least, be inconvenient, and would probably result in such a handicap as to render useless the transmission line having such limitations.

Ralph D. Mershon: I have not had an opportunity to give this paper nearly the study I wanted to and that I intend to. There are one or two points in regard to it I would like to mention. If I remember rightly, Dr. Fleming made, at a much earlier date than any of those mentioned, a study of the effects of the distributed inductance and capacity of a transmission circuit.

Mr. Thomas makes mention of a paper by myself, and misinterprets it a little, I think. In that paper it was assumed that with unity power-factor at the middle of the line, or approximately at the middle of the line, the line loss would differ little from that for unity power-factor throughout the line and that such difference as did exist would be negligible in the problem I was considering. Such assumption greatly simplified the problem, and is permissible where large amounts of power are transmitted. It was also assumed that the synchronous motors would be designed to give the requisite voltage regulation.

This brings up a point which, so far as I have been able to study his paper, Mr. Thomas seems to have neglected. A synchronous motor used at the end of a line to regulate the power-factor of the line is not equivalent to a condenser; it behaves quite differently. When the voltage increases on a condenser the current to the condenser increases. When the voltage impressed upon an over-excited synchronous increases, the leading current to the motor *decreases*, and with further increase of impressed voltage the current passes through zero and then becomes a lagging current which *increases* with the impressed voltage. As a result, such a motor may improve or may impair the regulation; meaning by *regulation* the inherent regulation—the maximum change in voltage if full load, say, be thrown off suddenly and no adjustment made in the system. If the inherent regulation of the line, and the synchronous motor at the end of it, happen to be the same, then the regulation of the combination of line and motor will be that of either. If the inherent regulation of the line be worse than that of the synchronous apparatus, then the resultant regulation will be better than that of the inherent regulation of the line, and not so good as that of the synchronous apparatus, and conversely. Synchronous apparatus tends to make the regulation of the system the same as that of itself; better or worse as the case may be.

There would be great mechanical objection to the split conductor Mr. Thomas proposes. There may be another objection in the limitation its use may put upon the permissible line voltage, as governed by the critical point or point at which the air begins to break down, as against the voltage which could be used if a single conductor of larger diameter were employed. The mechanical objections Mr. Thomas has already mentioned, but I think that when it comes to making figures as to the increased cost involved in the line structures and construction generally by the use of three cables, it will be found that, because of the greater wind forces resulting, especially if the cables gather sleet, the increased cost will make the use of the split conductor extremely objectionable, if not absolutely prohibitive.

Henry W. Fisher: About a year ago we had occasion to make some calculations on a proposed 60-mile cable transmission line to operate at 60,000 volts. The power to be delivered was 42,000 kw. at 80 per cent power-factor. On account of the high capacity and low self-induction of the line the calculated power-factor at the generator was practically 100 per cent. In some calculations the load was leading, in others lagging.

Calculations were made with half the capacity concentrated at each end and also, according to Dr. Steinmetz' recommendation, with one sixth of the capacity at each end and two thirds in the middle.

The calculated results based on both of these assumptions were not materially different.

J. B. Whitehead (by letter): The use of approximate formulas should invariably be safeguarded by consideration: first, of the range of values within which the approximation holds true, and the magnitude of variation due to the correcting factors without this range; and, secondly, the degree to which experiment and experience has shown the approximate formulas to be sufficiently correct.

The author of these papers has performed a valuable service in presenting his wave formulas as checks upon the use of the split-capacity formula. Considering his comparison of the two types of formula as given in Table I, one is surprised and rather relieved to find the small differences that are involved. It should be pointed out, however, that the author has considered ohmic resistance, inductance, and capacity only. The losses between lines, over insulators, and in other kindred phenomena have been neglected. These losses would appear as a conductance or parallel connected resistances in the development of a formula taking them into account. The suggestion of the author to subdivide the individual wires of the line into several others would naturally lead to an increase in the insulator loss, and without further modification would also lead to circulating or secondary currents in the several branches of one line due to inductive action of the others. My feeling after reading these two papers is that a series of accurate measurements on existing lines would be of first importance for answering the questions which are raised.

I find the author's standpoint in the description and explanation of the phenomena as given in the first paper rather confusing, by reason of the apparent separation of the energy into three components. I venture to call attention to several apparent inconsistences which result. Energy and voltage drop or rise appear to have the same physical dimensions. It may also be asked from what quantity involved are the phases of various currents, electromotive forces, and energies to be reckoned; that is, with reference to what quantity are the "leading and lagging " energies leading and lagging? We are asked on one page to note that the leading and lagging energies are equal and opposite when the load power-factor is equal to one, and then on the next page we are cautioned to remember that the leading and lagging energies have no necessary relation to the leading or lagging current in the load. We are also asked to imagine that the energy for charging the line flows against the energy which represents the power transmitted. Is it not the case that in the transmission of power the resultant flow of energy is in one direction? The distinction is also drawn between true power and leading and lagging energies, the inference being that these latter are wattless. My question then is, why call them energies? We are also told that in one instance the synchronous machines at the receiving end supply all of the load lagging current except enough to charge 300 miles of the line.

In calling attention to these few difficulties of my own, I have no wish to depreciate the author's valuable contribution to our knowledge of long-distance transmission problems. I wish only to make a plea for the retention of current and electromotive force as standards of reference where variation with time is involved, and the direction of the resultant flow of energy where variations in space are involved. If the instantaneous energy is of interest, Poynting's theorem based on Maxwell's equations that the flow of energy is in the medium and perpendicular at all points to the electric and magnetic vectors makes it possible to picture the flow of energy at any point in a line in terms of the instantaneous values of current and electromotive force.

C. F. Scott: I think Mr. Thomas deserves special credit for taking what is apparently a simple problem, which most of us have probably regarded as having been satisfactorily solved, and going into it deeply and working it out more fully, to determine what results may be encountered when new conditions may be reached in the future. It is the experience in all power transmission work, that when we go up to a higher voltage, new points, which have sometimes had an unimportant bearing, or which apparently have not been thought of before, force themselves into great prominence; and it is well to go over these problems very carefully, as is done here, so as to determine actually what these conditions are.

A few points have been raised in the discussion which it seems to me are taken care of. Mr. Lincoln, for example, suggested that the nature of the load was such that it was hard to get stable and definite conditions, and that if the conditions were properly established for one load, they will not be right for other loads. The important condition is full load, so that the line will transmit the full-load energy with a high efficiency; it is often of minor consequence what the efficiency is at lesser loads.

Mr. Mershon raised the point that synchronous machines are different from condensers, because when delivering different amounts of current, they were liable to give different voltages. But as Mr. Thomas will use the synchronous machine at the receiving end of the line, it is to be loaded at practically constant potential, and therefore it seems to me that these variables will probably not appear. The synchronous machine at the end of the line is not dependent upon the various voltages and currents coming in over the line, but it of itself is to be made the important voltage regulating element in the system. We may consider, I think, that we have two kinds of current in the system, one, the power current, comes from the generating station, and the other current that has been called by various names this morning. I will, however, use the familiar term wattless current. That has to be supplied from somewhere also, and Mr. Thomas supplies it at the receiving end. Consequently, the power current will be generated at one end of the line, and the wattless current at the other end of the line by synchronous motors, and the latter may control the voltage at the receiving end, which appears an ideal relation.

It occurs to me that possibly two wires as a single conductor would accomplish the same effect as the three proposed by Mr. Thomas.

I have been impressed with the mathematical part of this paper. I think Mr. Thomas is to be congratulated in not mixing the two things together—the engineering conclusions and the mathematical methods. I was in New York a few days ago, and I met a consulting engineer who said he had been going over these papers and found they could be very much simplified. The first gentleman who opened the discussion this morning said that the matter given in the papers could be presented in a much simpler way. He went to the blackboard to prove it. The next speaker said the matter could be presented in a much simpler way, and he covered the blackboard twice. Another professor said it was a simple thing to buy a book and read all about it, and Dr. Steinmetz then said the purpose of all this mathematical demonstration is to show that it is really not needed at all.

W. A. Del Mar: I wish to call attention to the fact that in neglecting leakage Mr. Thomas has missed an opportunity to make his equations homogeneous and has complicated rather than simplified them by this omission. A set of equations due to Dr. H. Pender* takes leakage into account with the result that the final equations are more simple than those given in the paper under consideration.

Furthermore, Dr. Pender's solution is considerably simplified by the introduction of the power-factor angles of the line impedance and leakage admittance. The equations are put in such form as to give a clear physical conception of the processes, a quality lost by Mr. Thomas' rather lengthy expressions. It is unfortunate that Dr. Pender's article did not appear in the PROCEEDINGS where it could be discussed and freely compared with Mr. Thomas' paper and I hope that this brief contribution will serve to attract the attention of the Institute members who may have read the latter and not the former.

A. E. Kennelly: These papers are of great importance, if only because they show how much labor is involved in the computation of the voltage and current distribution over a long line having distributed resistance, inductance, leakance and capacity, when hyperbolic functions are avoided. In the opening paragraphs of the first paper, the author intimates that the methods which have been suggested hitherto for making such computations are long and unpractical. He proceeds to offer what he considers to be practical working formulas for working out such problems. These practical formulas recommended to us as superior to all preceding formulas are collected in one place.

There can be no doubt that the voltage and current distribution over long lines worked at a single alternating-current frequency in the steady state can be computed by these formulas, and the paper will be useful to engineers if only in the collection of these formulas. It is, however, open to discussion whether these formulas are the best for engineers. These working formulas are so long that the voltage and current equations have first to be split into two parts (V_0 and $V_{\frac{\pi}{2}}$), or (I_0 and $I_{\frac{\pi}{2}}$), the square root of the sum of whose squares is the final voltage or current; while the formula for each component is then so long that it has to be printed lengthwise to the page. It is here contended by the speaker that such methods of computation are deterring and forbidding. They are fearful even to look upon, and the chances of making numerical mistakes in such long unwieldy equations are comparatively great. Fortunately, there are much simpler formulas for reaching the same results.

**Electrical World*, July 8, 1909.

If the voltage to be supplied at the distant end of a line is e volts and the current to be supplied there is i amperes, at a given power-factor and phase-angle with respect to e; then it has been shown by the speaker* that the voltage E and current I at the sending end of the line are respectively:

$$E = e \cosh \theta + i\, z_0 \sinh \theta \qquad \text{volts} \angle \quad (1)$$

$$I = i \cosh \theta + (e/z_0) \sinh \theta \qquad \text{amperes} \angle \quad (2)$$

where z_0 is the surge impedance of the line:

$$z_0 = \sqrt{\frac{r+j\,l\,\omega}{g+j\,c\,\omega}} \qquad \text{ohms} \angle$$

or as a first approximation

$$z_0 = \sqrt{\frac{l}{c}} \qquad \text{ohms}$$

and $\theta = L\,\alpha$ is the "hyperbolic angle" subtended by the line where L is the length of the line in miles or km. and α is the attenuation constant:

$$\alpha = \sqrt{(r+j\,l\,\omega)\,(g+j\,c\,\omega)} \qquad \text{"hyperbolic radians" per}$$

mile or km.

also r = the linear resistance of the line (ohms per mile or km.)
l = the linear inductance of the line (henrys per mile or km.)
g = the linear leakance of the line (mhos per mile or km.)
c = the linear capacity of the line (farads per mile or km.)
$\omega = 2\,\pi\,n$ = the angular velocity (radians per sec.)
n = frequency impressed on line (cycles per second).
$j = \sqrt{-1}$

Equations (1) and (2) are the equivalent of Mr. Thomas' formulas (40), (41), (42), (43).

If we should attempt to solve plane triangles, in the regular work of surveying, without the use of circular functions, (circular sines, cosines, tangents, etc.,) that is, without the use of trigometrical tables, we could do it by roundabout, long and tedious methods, but the contrast between such methods and those we actually use would be marked. Similarly, hyperbolic trigonometry is as natural and as essential to alternating-current line computations as is ordinary circular trigonometry to the surveyor's work. Hyperbolic trigonometry is just as easy as circular trigonometry, and can be grasped and handled practically with very little extra effort by the engineer who already grasps and handles circular trigonometry. It is true that our tables of hyperbolic sines cosines, tangents, etc. of vector or complex arguments are still very deficient; but even when we have to work out the hyperbolic sines and cosines of formulas (1) and (2) for ourselves, without aid from tables, I contend that these formulas are much more practical, direct, and easy to handle without mistakes, than the long formulas of the paper just read.

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* "On the Fall of Pressure in Long-Distance Conductors," by A. E. Kennelly. *Electrical World*, Vol. XXIII, No. 1, p. 17, Jan. 6, 1894. also *The Electrician*, London, Vol. 32, Jan. 5, 1894, pp. 239–240. "Resonance in Alternating-Current Lines," by E. J. Houston and A. E. Kennelly. TRANSACTIONS American Institute Electrical Engineers, Vol. XII, pp. 133—159, April 17, 1895.

Hyperbolic tables are available already, however, in the following cases:

(1) where $\omega = 0$, or direct currents are used.

(2) where $1 = 0$ and $g = 0$*; or in well insulated cables of negligible inductance.

(3) where $r = 0$ and $g = 0$; or where the line has negligible conductor and dielectric losses.

It is to be hoped that, before long, suitable tables of hyperbolic complex quantities may be available for engineers. Meanwhile, however, a hyperbolic sine or cosine of the complex angle $\boldsymbol{\theta}$, subtended by a line, can be computed by regular rules in a few minutes of time.

As pointed out in the papers before us, it is unnecessary in the great majority of cases to compute alternating-current line voltages and currents by the accurate formulas; whether those formulas be as given in (40), (41), (42), and (43) or those just given at (1) and (2) above. Lines are not long enough and fundamental frequencies are not high enough in power transmission work to make this refinement necessary. It is quite sufficient either to lump all the leakance and capacity in one condenser at the electrical middle point of the line; or, as in the paper, to split it into two equal condensers, one at each end of the line, and then to treat the line as a choking coil with condenser leak or leaks. If, however, higher harmonic frequencies have to be considered in long power-transmission line, it may be necessary to use the correct formulas of distributed capacity. Moreover the correct formulas are nearly always necessary in telephony, even on fairly short lines, owing to the high frequencies there employed.

The speaker has shown that the Π — conductor, or split-condenser representation of a line, may be readily corrected for the lumpiness-error; so as to give correct results, just as though the fuldistribution-formulas had been used.* The correct values of the equivalent T and equivalent Π are given below:

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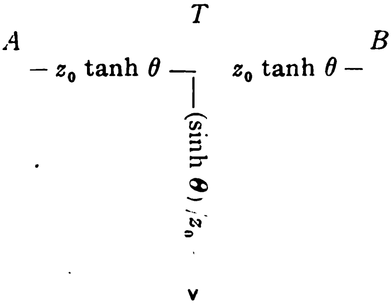
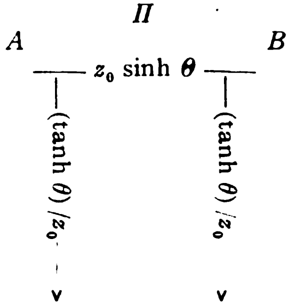
* The Alternating-Current Theory of Transmission Speed; and Table appended thereto. International Electrical Congress of St. Louis, 1904, Vol. I, pp. 68—105.





Here A and B are the terminals of the equivalent line, and $\theta = \boldsymbol{\theta}/2$, or is the hyperbolic-angle subtended by half the line. The total line impedance of the T is $2\,z_0 \tanh \theta$ and of the Π is $z_0 \sinh \boldsymbol{\theta}$ ohms. The total admittance of the capacity and leakage in the T is $\dfrac{\sinh \boldsymbol{\theta}}{z_0}$ mhos and of the Π, $\dfrac{2\ \tanh \theta}{z_0}$ mhos. Since the corresponding impedances and admittances in the uncorrected or nominal T are $2\,z\,\theta$ and $\boldsymbol{\theta}/z_0$; while for the nominal Π they are respectively the same; viz., $z_0\,\boldsymbol{\theta}$ and $2\,\theta/z_0$; it follows that the lumpiness-correcting operators are the vector ratios $\dfrac{\tanh \theta}{\theta}$ and $\dfrac{\sinh \boldsymbol{\theta}}{\boldsymbol{\theta}}$, which are 1 for indefinitely short lines; but which may reach either large or small positive or negative values when θ and $\boldsymbol{\theta}$ are large.

These formulas, for the correct or equivalent-Π, form a fitting addition to the formulas in the paper on the split condenser method, or nominal-Π, method.

It is pointed out in the paper that the linear capacity of a split-conductor circuit is increased as its linear inductance is diminished. It is not generally known, and perhaps may not have been noticed by electrical engineers, that there is a very simple proposition connecting the linear inductance and capacity of any uniform conducting aerial circuit; namely, that the linear capacity in C. G. S. electrostatic units is the reciprocal of the external linear inductance in C. G. S. magnetic units. If l be the linear inductance of a uniform line in abhenrys per cm., counting only the effect of flux external to the conductor, and ignoring whatever additional inductance may be due to flux

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[*] Artificial Lines for Continuous Currents in the Steady State by A. E. Kennelly. *Proceedings of the American Academy of Arts and Sciences.* Vol. 44, No. 4. Nov. 1908, pp. 97—130.

The Influence of Frequency on the Equivalent Circuits of Alternating Current Transmission-Lines, by A. E. Kennelly. *Electrical World.* Jan. 21, 1909. Vol. 53, No. 3.

inside the wire; then if c be the linear capacity of the line in statfarads per cm., ignoring the capacity of the insulators, or other accidental condenser loads; then $l = 1/c$ or $c = 1/l$. This proposition depends on the fact that the velocity of electromagnetic wave propagation over any such aerial line is theoretically, $v = 3 \times 10^{10}$ cm./sec. very nearly and that, thus far, experimental observations have confirmed the theory. Moreover, it is known that this velocity of transmission $v = \frac{1}{\sqrt{l\,c}}$ cm/sec. where l and c are the linear inductance and capacity of the line both in magnetic units; *i.e.* in abhenrys per cm. and abfarads per cm. Consequently $c = 1/l\,v^2$ abfarads per cm.; but if we multiply the number of abfarads per cm. by v^2, we obtain, by definition, the same linear capacity expressed in statfarads per cm.; so that $c = 1/l$ statfarads per cm.

This proposition enables us, in any uniform distribution of overhead line conductors; unsplit or split, to choose whether we shall compute the external linear inductance of the system, or the linear capacity, and then the other quantity follows as a simple reciprocal. Correction must subsequently be made for the internal inductance of the conductors, and for any load condensers, or insulator capacities, in the system. In the case of the paper before us, it is the inductance of the new conductor arrangement which has been worked out; so that the capacity follows at once, and clearly increases as the inductance of the line has been diminished by the wire-splitting.

P. H. Thomas: Mr. H. G. Stott has made a valuable suggestion in connection with the starting of non-synchronous generators; namely, that the machines can be built for both synchronous and non-synchronous operation, the revolving field being provided with the ordinary direct-current magnetization, and with the short-circuit squirrel-cage winding in addition. The line could then be started up from the direct-current, independent-field excitation, and when the synchronous machines were started the field circuit could be opened and the short-circuit winding would make the machine operate as a non-synchronous generator.

In the discussion a good deal of time is spent on the terms "leading energy" and "lagging energy." Under the circumstances I do not think it worth while to spend much time in further discussing those points. Briefly, the reason I use the terms is this: the effect of the capacity is a leading current in regard to the generator; the effect of the inductance is a reactance voltage. They cannot be spoken of both as leading or lagging current, leading or lagging voltage; they are different in character but both represent energy, and they balance as energy. A volt cannot be balanced against an ampere, but the energy of one phase can be balanced against the energy of another phase. Both represent real energy, but not of course energy usable in the load circuits.

I wish to call attention to one very excellent equation or formula for the calculation of the line not referred to in the paper, and which takes account of distributed inductance and capacity. This is given by Dr. Kennelly in the *Electrical World* in 1895. This formula makes use of vectorial quantities and involves hyperbolic functions. While extremely simple in form and very advantageous in theoretical analysis, its use requires a knowledge of vectorial algebra and hyperbolic functions and is not nearly so simple for numerical calculations as would seem from its form.

I wish to say again, as stated in the paper, that the derivation here given is not intended as a novel mathematical procedure, but merely as a straightforward derivation by the ordinary mathematical processes in common use among the majority of engineers, of a practical formula easily understood and conveniently used in engineering calculations.

Mr. Mershon has raised the question whether the relatively small sized individual wires of the divided conductor method described in the first paper would mean serious loss directly into the atmosphere. While I have no actual data on which to base an opinion, I should expect a gain rather than a loss in this feature since the divided conductor acts, in other relations, in effect like a larger conductor.

T. Dalemont (by letter): The method set forth by Mr. P. H. Thomas for the calculation of high-tension lines with capacity presents the advantage of doing away with vector diagrams into which errors so easily creep. But in this calculation the exponential and hyperbolic functions are not eliminated. It occurs to me that it might be of interest to call attention to a very simple method for calculating lines where the capacity effects are not negligible, and where they are to be considered as evenly distributed along the line. This method was suggested by Mr. André Blondel,* as far back as 1906. He based it on the fact that at every point of a line fed at the extremities by a sine electromotive force, the oscillations of the electromotive force and the current are both sine, and that each of them is the result of two waves flowing in opposite directions. One of these two waves is produced at the generating point, while the other is a reflex of the first, after this latter has reached the extremity of the line. Passing along the line, they both undergo simultaneously a damping and a phase rotation resulting from the combined effect of the self-induction and the capacity.

The equations of the second degree, differential equations of the tension, and of the current at point x from the end of the line are well known, and their solutions are expressed as follows:

$$V = A_1 e^{ax} \sin (p t + b x - \alpha) + B_1 e^{-ax} \sin (p t - b x - \beta) \qquad (1)$$

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* C. F. A. Blondel, Calcul designes avec self-induction et capacité. *Eclairage Electrique*, 1906, XLIX, p. 121. *Lumiere Electrique* T. I. (2d serie) p. 395.

In this, A and B are constant values and α, β are constant phase angles determined by the conditions at the extremities. On the other hand we have:

$$a = \frac{1}{\sqrt{2}} \sqrt{-p^2\,c\,l+r\,g+\sqrt{(p^2\,l\,c-g\,r)^2+(p\,c\,r+p\,l\,g)^2}}$$

$$b = \frac{1}{\sqrt{2}} \sqrt{p^2\,c\,l-r\,g+\sqrt{(p^2\,l\,c-g\,r)^2+(p\,c\,r+p\,l\,g)^2}}$$

In this r is the resistance per unit of length,
L the inductance, " "
c the capacity " "
g the conductance (corresponding for instance to the losses by ionization)
p the pulsation of the current.

The foregoing may be easily verified, by differentiating the equation of V relatively to x and t and introducing the values obtained into the differential equation (1) given by Mr. Thomas, (equation (1)). Another term "$r\,g\,v$" must however be added to the second member if the conductance is negligible.

The developments of the transformation are the same as those which Mr. Thomas mentions, and the equations are not altogether different from his. We see for instance that $b = \frac{p}{v'}$ where v' is one of the values of v deduced from equation 10.

In the same way, we find for the current

$$i = \frac{A_1}{m} e^{ax} \sin\left(p\,t+b\,x-\alpha\underset{+\gamma}{+}\right) \frac{B_1\,e^{-ax}}{m} \sin\left(p\,t-b\,x-\beta\underset{+\gamma}{+}\right) \quad (2)$$

where

$$m = \sqrt{\frac{a^2+b^2}{g^2+p^2\,c^2}}$$

$$\gamma = \text{arc}\,tg\,\frac{p\,c}{g} - \text{arc}\,tg\,\frac{b}{a}$$

m is therefore a factor of impedance. We may thus express the tension at any point at a distance x from the receiving end (and not from the generator end) by the sum of two vectors:

$$U_x = (A_1\,e^{ax})_{(+bx)} + (B_1\,e^{-ax})_{(-bx)}$$

The vectors $A_1\,e^{ax}$ and $B_1\,e^{-ax}$ having turned respectively through an angle of $(+b\,x)$ and $(-b\,x)$ from the position which each occupied for $x = 0$.

In the same way, the current at point x will give:

$$I_x = \frac{1}{m}\left[(A_1\,e^{ax})_{(bx+\gamma)} - (B_1\,e^{-ax})_{(-bx+\gamma)}\right.$$

To find the values of A_1 and B_1 we must make $x = 0$, giving $U_x = U_1$ and $I_x = I_1$ (1); U_1 is the star tension and I_1 the current in each wire at the receiving end.

We thus find:

$$[A_1] = \left[\frac{U_1}{2}\right] + \left[\frac{m\,I_1}{2}\right] \quad (\text{turned} - \gamma)$$

$$[B_1] = \left[\frac{U_1}{2}\right] - \left[\frac{m\,I_1}{2}\right] \quad (\text{turned} - \gamma)$$

These two expressions enable us to determine A_1 and B_1 by a simple diagram.

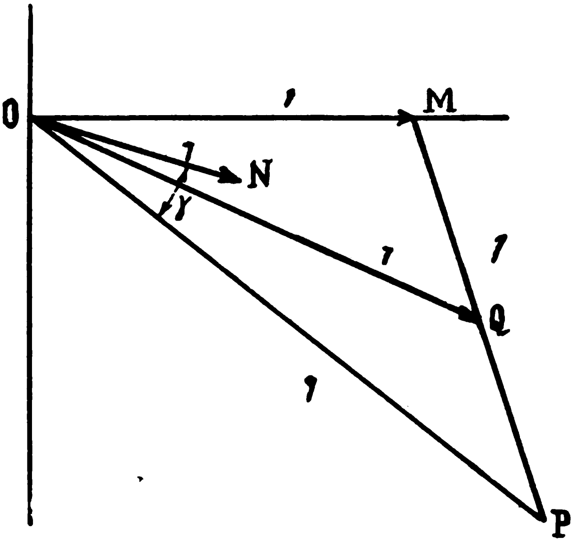

FIG. 1

In Fig. 1 $OM = U_1$; $ON = I_1$; $OP = m\,I_1$ turned through the angle $-\gamma$ and we obtain A_1 and B_1 in the lines OQ and MQ, which are half the sum and half the difference of the vectors U_1 and $m\,I_1$.

First case. Line at no load. $I_1 = 0$ (Fig. 2). The sum of A_1 and B_1 is U_1, and the difference, 0. Then $A_1 = B_1 = \frac{U_1}{2}$. Let $OM = A_1$, $MO = NM = B_1$ and $ON = U_1$. To find the values of the tension and the current at point x, we need only recall what has been said above.

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* I would here call attention to the fact that the equations are established on the supposition of a common return conductor of nil impedance, and that consequently U_1 is not the tension between the lines, but the tension between each wire and the centre of the assumed return.

In Fig. 2 $O\,p = \frac{U_1}{2} e^{ax}$, vector turned through the angle $(+b\,x)$ from 0, is drawn, and in the same way $P\,q = \frac{U_1}{2} e^{-ax}$. In carrying $p\,r = p\,q$, we obtain $o\,r = m\,I_x$, and finally $o\,s' = \frac{o\,r}{m}$ turned through an angle of γ, gives the value of I_x.

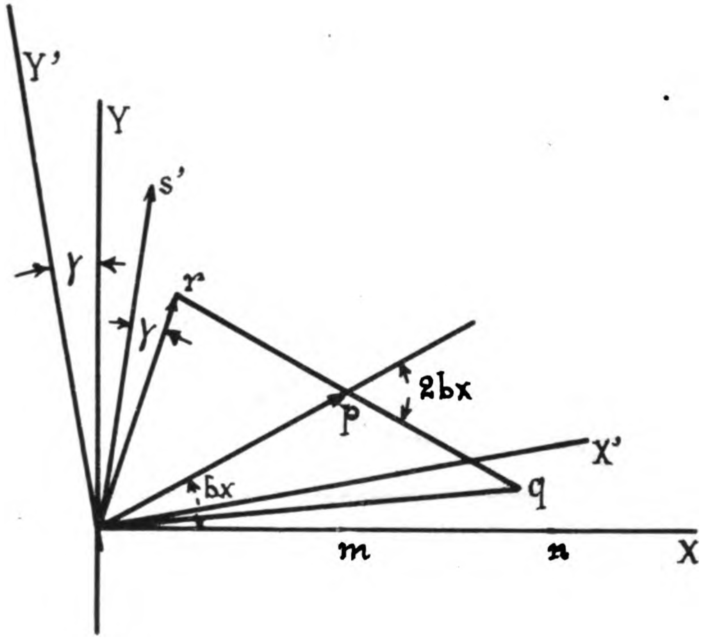

FIG. 2

Second case. Line at short-circuit. $U_1 = 0$ (Fig. 3). Let $O\,N = I_1$ the short-circuit current, and $A_1 = B_1 = O\,M = \frac{I_1}{2}$.

We obtain as above, at distance x from the receiving end,

$$O\,p = \frac{I_1}{2} e^{ax} \qquad P\,r = \frac{I_1}{2} e^{-ax}$$

The vector $O\,q' = J_x$ gives the short-circuit current in size and phase at point x.

$O r = \frac{1}{m} V_x$. V_x is the short-circuit tension at point x, but this vector must be multiplied by m and turned through the angle $-\gamma$ to obtain V_x in size and phase.

It will be noticed that the vector A_1 may be considered as the resultant of the two components $\frac{U_1}{2}$ and $\frac{m\,I_1}{2}$, the latter turned through an angle of $-\gamma$.

The same applies to B_1.

Finally U_x may be considered as the resultant of 4 vectors:

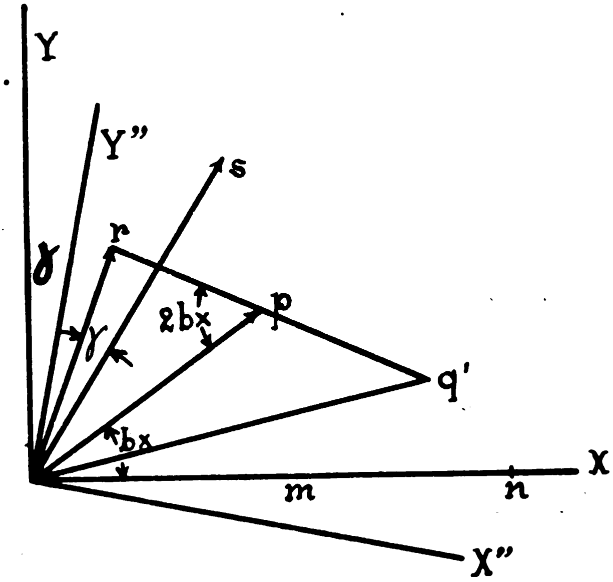

FIG. 3

$\frac{U_1}{2} e^{ax}$ turned through the angle $+b\,x$

$\frac{U_1}{2} e^{-ax}$ " " " " $-b\,x$

$\frac{m\,I_1}{2} e^{ax}$ " " " " $+b\,x$

$\frac{m\,I_1}{2} e^{-ax}$ " " " " $-b\,x$

It will be seen in any case, that if we make $A_1 = B_1 = \frac{U_1}{2}$

the two first terms would have for resultant, the tension obtained at the distance x when $I_1 = 0$ (at no load). which would be.

$$(U_x') = (A_1\, e^{ax})\ (b\, x) - (B_1\, e^{-ax})\ (-b\, x).$$

In the same way, if we make $A_1 = B_1 = \frac{I_1}{2}$ that is $U_1 = 0$, (short-circuit), the resultant of the two last terms will be:

$$(U''_x) = (A_1\, e^{ax})_{(bx)} - (B_1\, e^{-ax})_{(-bx)}$$

By a similar method, the current is brought back to its two components at no load and at short-circuit.

We may finally determine the resultant vectors of the current and tension by placing the two Fig. 2 and 3 on each other and giving them a common pole.

The analytical expressions of the vectors may be easily deduced from these diagrams when we use the auxiliary axis, which are drawn in the Fig. 2 and 3. The components of the tension at point x are $o\, q$ in Fig. 2 and $o\, s$ in Fig. 3.
where,

$$O\, q = U_1 \sqrt{\frac{\cos h.\ 2\, a\, x - \cos 2\, b\, x}{2}}$$

and

$$o\, s = m\, I_1 \sqrt{\frac{\cos h.\ 2\, a\, x + \cos 2\, b\, x}{2}}$$

and the components of the current are $o\, q'$ in Fig. 3 and $o\, s'$ in Fig. 2.

$$o\, q' = I_1 \sqrt{\frac{\cos h.\ 2\, a\, x - \cos 2\, b\, x}{2}}$$

$$o\, s' = \frac{U_1}{m} \sqrt{\frac{\cos h.\ 2\, a\, x + \cos 2\, b\, x}{2}}$$

The vector angles may also be determined:

(angle between $o\, q$ and $o\, s$) $\psi = \operatorname{arc} t\, g \left(\frac{\sin 2\, b\, x}{\sin h\ 2\, a\, x} \right) - (\gamma + \phi_1)$

(angle between $o\, q'$ and $o\, s$) $\Sigma = \operatorname{arc} t\, g \left(\frac{\sin 2\, b\, x}{\sin h\ 2\, a\, x} \right) + \gamma + \phi_1$

In these expressions ϕ_1 is the phase angle at the receiving end, or in other words $\cos \phi_1$ is the power-factor of the receiving circuit. All these expressions will be met with in calculating the following line.

Let us take the line which Mr. Thomas gives as an example:

Transmitted power	40,000 kw.
Length of transmission	700 miles
Frequency	25 cycles
Tension between two wires at receiving end	150,000 volts
Power-factor	.918
Distance of wires	12 ft.

In his calculation, Mr. Thomas replaced the three-phase line by a single-phase line which transmitted half the power with the same tension, as that existing between wires. In the present calculation, the three-phase line was replaced as already mentioned, by a single-phase line, one conductor of which was similar to each of the conductors in the three-phase line, while the other had a nil resistance. We see that this should give the same results.

Let V_1 be the tension between wires of the three-phase line,
I_1 the current in each wire
$\cos \phi_1$ the power factor of the distributed power.

Half of the power transmitted by the single phase will be:

$$\frac{\sqrt{3}}{2} \quad V_1 I_1 \cos \phi_1$$

With the tension V_1 between wires, the current will be:

$$I_1' = \frac{\sqrt{3}}{2} I_1$$

and the tension drop:

$$[V'] = [I_1' z'] = \left[\frac{\sqrt{3}}{2} \quad I_1 z' \right]$$

In the case of a single-phase line with an assumed return of nil resistance, the tension here called "star tension" is: $V_1'' = \dfrac{V_1}{\sqrt{3}}$ and the current in the wire is I_1. The tension drop is $[V''] = I_1 z'' = \frac{1}{2} I_1 z'$, the same therefore as in the preceding case.

We first calculated the current in each wire

$$I_1 = 167.5 \text{ amperes,}$$

and the star tension at the receiving end, $U_1 = 86.700$ volts. We will adopt the same conductor as that employed by Mr. Thomas.

The resistance r per mile of line is 0.085 ohm.
" reactance " " " " 0.309 "
" impedance " " " " 0.321 "

Admittance per mile, $w = \sqrt{g^2 + p^2 c^2}$

If g is neglected, we have: $w = p\,c = 2.386 \quad 10^{-6}$

We next calculated the auxiliary constant:

$$q = p^2\, l\, c - g\, r \quad \text{or } p^2\, l\, c \quad \text{if } g = 0$$

In the present case, we have $q = 0.737 \quad 10^{-6}$

The damping coefficient:

$$a = \sqrt{\frac{w\, z - q}{2}} = \sqrt{\frac{2.386 \; 10^{-6} \times 0.321 - 0.737 \; 10^{-6}}{2}}$$

$$= 0.12 \; 10^{-3}$$

$$b = \sqrt{\frac{w\, z + q}{2}} = 0.865 \; 10^{-3}$$

Coefficient of influence of the current on the electromotive force: $m = \sqrt{\frac{z}{w}} = 366.$

Auxiliary factors: (x being here the net length of the transmission, 700 miles).

$$\alpha = \sqrt{\frac{\cos h\, 2\, a\, x + \cos 2\, b\, x}{2}} = 0.825$$

$$\beta = \sqrt{\frac{\cos h\, 2\, a\, x - \cos 2\, b\, x}{2}} = 0.572$$

Auxiliary angles:

$$\gamma = \text{arc}\, t\, g \frac{p\, c}{g} - \text{arc}\, t\, g \frac{b}{a} = \frac{\pi}{2} - \text{arc}\, t\, g \left(\frac{432}{59}\right) = 8^\circ$$

$$g = \text{perditance} = 0$$

$$\sigma = \text{arc}\, t\, g \left[\frac{\sin 2\, b\, x}{\sin h\, 2\, a\, x}\right] = \text{arc}\, t\, g \left[\frac{0.565}{0.87}\right] = 79^\circ\, 40'$$

We find therefore the following auxiliary angles:

$$\psi = \sigma - \gamma = 71^\circ\, 40' \text{ and } \Sigma = \psi - \phi_1 = 48^\circ\, 10'$$
$$\Sigma = \sigma + \gamma = 87^\circ\, 40' \text{ and } X = \Sigma + \phi_1 = 111^\circ\, 10'$$

and finally,

$$\varepsilon = \text{arc}\, (t\, g\, h\, y\, p\, a\, x\, t\, g\, b\, x) = \text{arc} = 30^\circ\, 20'$$

Resulting vectors at beginning of line, transmitting tension at the end:

$U_1 = 86{,}700$ volts. $\qquad I_1 = 167$ amperes, 5

The star tension at the beginning of the line corresponding to

$$U_1 = U_0 = \alpha\, U_1 = 86.700 \times 0.825 = 71{,}500 \text{ volts}$$

The tension drop produced by the distributing current is

$$V_0 = 366 \times 0.572 \times 167.5 = 35{,}000 \text{ volts}$$

The angle δ of the tension U_0 and of the tension at the beginning of the line is given by:

$$tg\,\delta = \frac{V_0 \sin \Sigma}{V_0 + U_0 \cos \Sigma} = 0.274 \qquad \delta = 15^\circ\, 20'$$

The star tension at the beginning of the line is therefore $U_0' = \dfrac{V_0 \sin \Sigma}{\sin \delta} = 98{,}500$ volts and the tension between the wires is 170,500 volts. The current at the beginning, corresponding to that of the terminal point of the line is likewise:

$$I_0 = \alpha I_1 = 0.825 \times 167.5 = 138.5 \text{ amperes.}$$

The charging current at no load is:

$$J_0 = \frac{\beta}{m} U_1 = \frac{0.572}{366} \times 86{,}700 = 135 \text{ amperes}$$

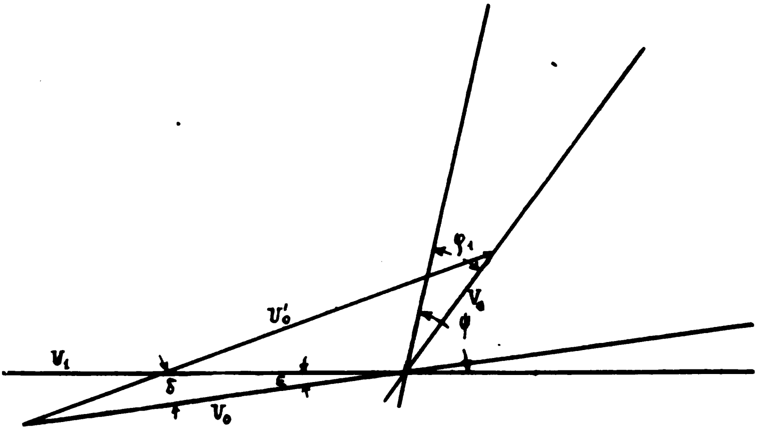

FIG. 4

On the other hand, we have:

$$tg\,\delta' = \frac{J_0 \sin X}{I_0 + J_0 \cos X} = 197 \quad \delta' = 54^\circ$$

The total resulting current at the beginning of the line is therefore:

$$J_0' = \frac{J_0 \sin X}{\sin \delta'} = 154.5 \text{ amperes.}$$

The power-factor at the generator end is $\cos \phi_0 = 0.90$.

Fig. 4 and 5 give the diagrams of the tensions and currents. We might note that a similar construction could be made for any value of x, that is to say for any point of the line.

This method would be quite simple, if all the hyperbolic functions were eliminated. To do this, their development in series might be made use of as has been done. This, however, introduces an approximation in the results.

Instead of maintaining the hyperbolic functions or their development in series, they may be easily transformed as follows:

$$\alpha = \sqrt{\frac{\cos h\, 2\,a\,x + \cos 2\,b\,x}{2}}$$

If we introduce into this, the value of cos hy. $2\,a\,x$ we easily find:

$$\alpha^2 = \frac{e^{4ax} + 1 + 2\,e^{2ax} \cos 2\,b\,x}{4\,e^{2ax}}$$

and finally,

$$\alpha = \sqrt{\frac{(e^{2ax} + \cos 2\,b\,x)^2 + \sin^2 2\,b\,x}{4\,e^{2ax}}}$$

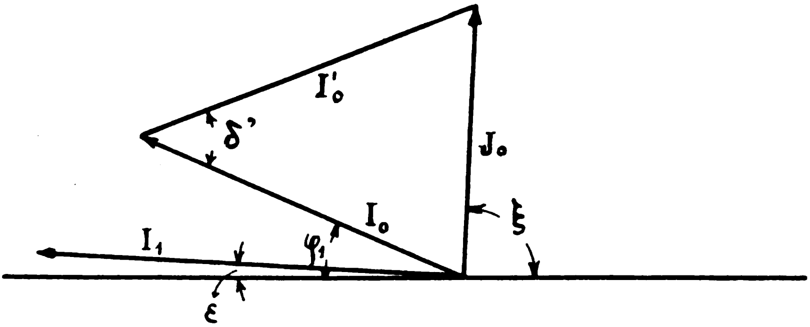

FIG. 5

In this expression, the exponential function e^{2ax} may be calculated without any difficulty. Moreover, this expression suggests a simple graphical method to determine the value of α if the exponential curve $Y = e^x$ has first been drawn in short limits of the value of x.

In the same way, we have:

$$\beta = \sqrt{\frac{(e^{2ax} - \cos 2\,b\,x)^2 + \sin^2 2\,h\,x}{4\,e^{2ax}}}$$

and

$$t\,g\,\sigma = \frac{2\,e^{2ax}}{e^{4ax} - 1} \sin 2\,b\,x$$

In these expressions the hyperbolic functions have disappeared.

Charles P. Steinmetz (by letter): With the very long high-voltage transmission lines that are now being considered, it is not safe to calculate the performance of the line by the approximate equations that have been used for the lines of moderate voltage and moderate length; but the numerical calculations should be made by using the complete equations of the transmission line, or at least the approximate calculations should be checked in a number of points by the exact equations. Although the complete equations of the transmission line appear complicated on first sight, numerical calculations can be made easily and rapidly by a systematic arrangement in tabulated form. However, even with 60-cycle lines several hundred miles long, satisfactory accuracy can still be derived by the approximation of substituting for the exponential functions of the complete equations the first terms of their series. The calculation is essentially simplified thereby.

I. Investigation

The voltage $\underset{\cdot}{E}$ and current $\underset{\cdot}{I}$ at any point l of the transmission line is given, in the usual representation by complex quantities, by the equations.*

$$\left.\begin{aligned} \underset{\cdot}{I} &= \underset{\cdot}{Y}\{\underset{\cdot}{C}_1\,\varepsilon^{+\alpha l}(\cos\beta l - j\sin\beta l) - \underset{\cdot}{C}_2\,\varepsilon^{-\alpha l}(\cos\beta l + j\sin\beta l)\} \\ \underset{\cdot}{E} &= \underset{\cdot}{V}\{\underset{\cdot}{C}_1\,\varepsilon^{+\alpha l}(\cos\beta l - j\sin\beta l) + \underset{\cdot}{C}_2\,\varepsilon^{-\alpha l}(\cos\beta l + j\sin\beta l)\} \end{aligned}\right\} \quad (1)$$

where:

$$\begin{aligned} Z &= r - j\,x = \text{line impedance per unit length,} \\ Y &= g - j\,b = \text{shunted admittance of the line per unit length,} \\ z &= \sqrt{r^2 + x^2} \\ y &= \sqrt{g^2 + b^2} \\ V &= \alpha - j\,\beta \\ \alpha &= \sqrt{\tfrac{1}{2}(z\,y + r\,g - x\,b)} \\ \beta &= \sqrt{\tfrac{1}{2}(z\,y - r\,g + x\,b)} \end{aligned} \quad (2)$$

the distance l is counted towards rising power; that is, from the receiving end towards the generator, and $\underset{\cdot}{C}_1$ and $\underset{\cdot}{C}_2$ are integration constants.

Choosing as unit length the entire line, $l = 0$ gives $\underset{\cdot}{I}_0$ and $\underset{\cdot}{E}_0$ at the receiving end, and $l = 1$ gives $\underset{\cdot}{I}_1$ and $\underset{\cdot}{E}_1$ at the generator end of the line, and Z is the total impedance, Y the total shunted admittance of the entire line.

Neglecting the shunted conductance; that is, assuming the power consumed by leakage and electrostatic losses in the line as negligible compared with that consumed by the effective line resistance r — as is always done—gives:

$$\begin{aligned} \alpha &= \sqrt{\tfrac{1}{2}\,b\,(z - x)} \\ \beta &= \sqrt{\tfrac{1}{2}\,b\,(z + x)} \\ Y &= -j\,b \end{aligned} \quad (3)$$

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* *Transient Phenomena.* Section III, Par. 8, equations (21)

Substituting now into equations (1) the values:

$$\begin{aligned} V \underset{\cdot}{C}_1 &= \underset{\cdot}{A}_1 \\ V \underset{\cdot}{C}_2 &= \underset{\cdot}{A}_2 \end{aligned} \qquad (4)$$

$$\frac{V}{Y} = Z_0 = r_0 + j\,x_0$$

where, by (2) and (3):

$$\begin{aligned} r_0 &= \frac{\beta}{b} \\ x_0 &= \frac{\alpha}{b} \end{aligned} \qquad (5)$$

and denoting:

$$Z_0 \underset{\cdot}{I} = \underset{\cdot}{U} \qquad (6)$$

it is:

$$\begin{aligned} \underset{\cdot}{E} &= \underset{\cdot}{A}_1\, \varepsilon^{+\alpha l} (\cos\beta\, l - j \sin\beta\, l) + \underset{\cdot}{A}_2\, \varepsilon^{-\alpha l} (\cos\beta\, l + j \sin\beta\, l) \\ \underset{\cdot}{U} &= \underset{\cdot}{A}_1\, \varepsilon^{+\alpha l} (\cos\beta\, l - j \sin\beta\, l) - \underset{\cdot}{A}_2\, \varepsilon^{-\alpha l} (\cos\beta\, l + j \sin\beta\, l) \end{aligned} \qquad (7)$$

If then $\underset{\cdot}{E}_0$ and $\underset{\cdot}{I}_0$ denote voltage and current at the receiving end, for $l = 0$, and $\underset{\cdot}{E}_1$ and $\underset{\cdot}{I}_1$ denote voltage and current at the generator end, for $l = 1$, and:

$$\begin{aligned} Z_0 \underset{\cdot}{I}_0 &= \underset{\cdot}{U}_0 \\ Z_0 \underset{\cdot}{I}_1 &= \underset{\cdot}{U}_1 \end{aligned} \qquad (8)$$

equations (7) give:

Receiving end: $l = 0$,

$$\begin{aligned} \underset{\cdot}{E}_0 &= \underset{\cdot}{A}_1 + \underset{\cdot}{A}_2 \\ \underset{\cdot}{U}_0 &= \underset{\cdot}{A}_1 - \underset{\cdot}{A}_2 \end{aligned} \qquad (9)$$

Generator end: $l = 1$,

$$\begin{aligned} \underset{\cdot}{E}_1 &= \underset{\cdot}{A}_1\, \varepsilon^{+\alpha} (\cos\beta - j \sin\beta) + \underset{\cdot}{A}_2\, \varepsilon^{-\alpha} (\cos\beta + j \sin\beta) \\ \underset{\cdot}{U}_1 &= \underset{\cdot}{A}_1\, \varepsilon^{+\alpha} (\cos\beta - j \sin\beta) - \underset{\cdot}{A}_2\, \varepsilon^{-\alpha} (\cos\beta + j \sin\beta) \end{aligned} \qquad (10)$$

Since α is a small quantity even in very long lines, because in equation (3), b is small at 25 cycles, while $(z - x)$ is small at 60 cycles, $\varepsilon^{\pm\alpha}$ can be replaced by the first terms of its series:

$$\varepsilon^{\pm\alpha} = 1 \pm \alpha + \frac{\alpha^2}{3} \pm \frac{\alpha^3}{6} + \frac{\alpha^4}{24} \pm \ldots \qquad (11)$$

that is, by:

$$\varepsilon^{\pm\alpha} = 1 \pm \alpha \tag{12}$$

or, if a greater accuracy is desired, by:

$$\varepsilon^{\pm\alpha} = 1 + \frac{\alpha^2}{2} \pm \alpha \tag{13}$$

Substituting (13) into (10), rearranging, and then substituting (9), gives:

$$\begin{aligned} \underset{\bullet}{E}_1 &= \underset{\bullet}{E}_0 \, (a_1 - j\, a_2) + \underset{\bullet}{U}_0 \, (c_1 - j\, c_2) \\ \underset{\bullet}{U}_1 &= \underset{\bullet}{U}_0 \, (a_1 - j\, a_2) + \underset{\bullet}{E}_0 \, (c_1 - j\, c_2) \end{aligned} \tag{14}$$

where:

$$\begin{aligned} a_1 - j\, a_2 &= \left(1 + \frac{\alpha^2}{2}\right) \cos\beta - j\, \alpha \sin\beta \\ c_1 - j\, c_2 &= \alpha \cos\beta - j \left(1 + \frac{\alpha^2}{2} \sin\beta\right) \end{aligned} \tag{15}$$

are line constants, independent of voltage, current, and power-factor.

Substituting (8) into (14) gives:

$$\begin{aligned} \underset{\bullet}{E}_1 &= \underset{\bullet}{E}_0 \, (a_1 - j\, a_2) + \underset{\bullet}{I}_0 \, (b_1 - j\, b_2) \\ \underset{\bullet}{I}_1 &= \underset{\bullet}{I}_0 \, (a_1 - j\, a_2) + \underset{\bullet}{E}_0 \, (d_1 - j\, d_2) \end{aligned} \tag{16}$$

where:

$$\begin{aligned} b_1 - j\, b_2 &= Z_0 \, (c_1 - j\, c_2) \\ d_1 - j\, d_2 &= \frac{c_1 - j\, c_2}{Z_0} \end{aligned} \tag{17}$$

hence, by (4), (5), and (15):

$$\begin{aligned} b_1 - j\, b_2 &= \frac{(\beta + j\,\alpha)\left(\alpha \cos\beta - j\left(1 + \frac{\alpha^2}{2}\right) \sin\beta\right)}{b} \\ &= \frac{\alpha\left(\beta \cos\beta + \left(1 + \frac{\alpha^2}{2}\right) \sin\beta\right) - j\left(\beta\left(1 + \frac{\alpha^2}{2}\right) \sin\beta - \alpha^2 \cos\right)}{b} \end{aligned} \tag{18}$$

$$d_1 - j\,d_2 = \frac{b\left\{\alpha \cos\beta - j\left(1 + \frac{\alpha^2}{2}\right)\sin\beta\right\}}{\beta + j\,\alpha}$$

$$= \frac{b\,(\beta - j\,\alpha)\left\{\alpha \cos\beta - j\left(1 + \frac{\alpha^2}{2}\right)\sin\beta\right\}}{\beta^2 + \alpha^2}$$

and as by (3):

$$\beta^2 + \alpha^2 = b\,z$$

it is: (19)

$$d_1 - j\,d_2 = \frac{\alpha\left(\beta\cos\beta - \left(1 + \frac{\alpha^2}{2}\right)\sin\beta\right) - j\left(\beta\left(1 + \frac{\alpha^2}{2}\right)\sin\beta + \alpha^2\cos\beta\right)}{z}$$

Thus, if:

e_0 = voltage at the receiving end of line,
i_0 = total current, consisting of the power current i_0' and the reactive current i_0'' (counted positive for lag), that is:

$$\underset{\cdot}{I}_0 = i_0' + j\,i_0''$$

voltage and current at the generator end of the line are given by the equations (16) as:

$$\begin{aligned} \underset{\cdot}{E}_1 &= e_0\,(a_1 - j\,a_2) + (i_0' + j\,i_0'')\,(b_1 - j\,b_2) \\ \underset{\cdot}{I}_1 &= (i_0' + j\,i_0'')\,(a_1 - j\,a_2) + e_0\,(d_1 - j\,d_2) \end{aligned} \qquad (20)$$

If in equations (1) the sign of l is reversed, the distance is counted toward rising power; that is, $l = 0$ gives generator voltage and current, e_1 and i_1, $l = 1$ gives receiving voltage and current, e_0 and i_0. The only change resulting herefrom is a reversal of the sign of α and β in equations (10) and (15), and thus a change of the sign of the second terms of (16) and (20):

$$\begin{aligned} \underset{\cdot}{E}_0 &= e_1\,(a_1 - j\,a_2) - (i_1' + j\,i_1'')\,(b_1 - j\,b_2) \\ \underset{\cdot}{I}_0 &= (i_1' + j\,i_2')\,(a_1 - j\,a_2) - e_1\,(d_1 - j\,d_2) \end{aligned} \qquad (21)$$

II. CONCLUSIONS

In a long-distance transmission line, voltage $\underset{\cdot}{E}_1$, current $\underset{\cdot}{I}_1$, and power-factor at the generator end can be accurately calculated from the voltage $\underset{\cdot}{E}_0$, current $\underset{\cdot}{I}_0$ and power-factor at the receiving end, and inversely, by the simple equations:

1. Generator voltage:

$$\underset{\cdot}{E}_1 = e_0 (a_1 - j\, a_2) + (i_0' + j\, i_0'')\,(b_1 - j\, b_2)$$

Generator current:

$$\underset{\cdot}{I}_1 = (i_0' + j\, i_0'')\,(a_1 - j\, a_2) + e_0 (d_1 - j\, d_2) \qquad (22)$$

where:

e_0 = voltage,
i_0' = power current,
i_0'' = reactive current at receiving end of line.

2. Receiver voltage:

$$E_0 = e_1 (a_1 - j\, a_2) - (i_1' + j\, i_2' \,(b_1 - j\, b_2)$$

Receiver current:

$$\underset{\cdot}{I}_0 = (i_1' + j\, i_1'')\,(a_1 - j\, a_2) - e_1 (d_1 - j\, d_2) \qquad (23)$$

where:

e_1 = voltage,
i_1' = power current,
i_1'' = reactive current at generator end of line, and:

$a_1 - j\, a_2$; $b_1 - j\, b_2$; $d_1 - j\, d_2$ are line constants, which are calculated once for all, and then permit the calculation of the performance of the line under all conditions of voltage, load and power-factor, from above equations (22) and (23).

These line constants are:

$$a_1 - j\, a_2 = \left(1 + \frac{\alpha^2}{2}\right) \cos \beta^\circ - j\, \alpha \sin \beta^\circ \qquad (15)$$

$$b_1 - j b_2 = \frac{\alpha\left(\beta \cos \beta^\circ + \left(1 + \frac{\alpha^2}{2}\right) \sin \beta^\circ\right) - j\left(\beta\left(1 + \frac{\alpha^2}{2}\right) \sin \beta^\circ - \alpha^2 \cos \beta^\circ\right)}{b} \qquad (18)$$

$$d_1 - j\, d_2 = \frac{\alpha\left(\beta \cos \beta^\circ - \left(1 + \frac{\alpha^2}{2}\right) \sin \beta^\circ\right) - j\left(\beta\left(1 + \frac{\alpha^2}{2}\right) \sin \beta^\circ + \alpha^2 \cos \beta^\circ\right)}{z} \qquad (19)$$

where:

$$\alpha = \tfrac{1}{2} \sqrt{b\,(z - x)}$$
$$\beta = \tfrac{1}{2} \sqrt{(z + x)} \qquad (24)$$

and in degrees:

$$\beta^\circ = 57.3\, \beta$$

and:

$$\left.\begin{aligned} r &= \text{resistance,}\\ L &= \text{inductance,}\\ C &= \text{capacity of total line; thus if:}\\ f &= \text{frequency,} \end{aligned}\right\} \quad (25)$$

$$\left.\begin{aligned} x &= 2\pi f L = \text{line reactance,}\\ b &= 2\pi f C = \text{shunted line susceptance,}\\ z &= r^2 + x^2 = \text{line impedance.} \end{aligned}\right\} \quad (26)$$

The possible error of the calculation is of the magnitude $\frac{\alpha^3}{6}$, hence, very small.

III. INSTANCE

As instance may be considered a 180-mile, three-phase transmission line, consisting of three wires No. 000 B. & S. G., 10 ft. between wires, operated at 60 cycles.

The line constants are:

$$r = 180 \times 0.33 = 60 \text{ ohms per line.}$$

$$L = 180\,(0.74 \log \frac{D}{R} + 0.08) = 383 \text{ mh.}$$

(where $D = 10$ ft. $= 120$ ins. $=$ distance between conductors, $R = 0.205$ ins. $=$ radius of conductor.)

$$\begin{aligned} f &= 60 \text{ cycles, hence:}\\ x &= 2\pi f L = 145 \text{ ohms,}\\ z &= r^2 + x^2 = 157 \text{ ohms.} \end{aligned}$$

$$C = 180 \times \frac{0.041}{\log \frac{D}{R}} \text{ mf., hence:}$$

$$b = 2\pi f C = 10^{-3} \text{ mhos.}$$

This gives:

$$\begin{aligned} \alpha &= 0.074\\ \beta &= 0.389 = 22.3^\circ \end{aligned}$$

and:

$$\begin{aligned} a_1 - j\,a_2 &= 0.928 - 0.028\,j\\ b_1 - j\,b_2 &= (0.055 - 0.143\,j)\ 10^{+3}\\ d_1 - j\,d_2 &= (-0.010 - 0.974\,j)\ 10^{-3} \end{aligned}$$

A. Determine generator voltage, current, and power-factor required to deliver 95,000 volts at non-inductive load.

95 kv. between lines gives $95 \div \sqrt{3} = 55$ kv. per line. Non-inductive load means $i_0'' = 0$.

Thus substituting: $e_0 = 55$, $i_0'' = 0$ into equations (22) gives:

$$\begin{aligned} E_1 &= 55\ (0.928-0.028j)+i_0'\ (0.055-0.143j). \\ &= \quad (50.9\ \ -1.5j)\quad +i_0'\ (0.055-0.143j)\ \text{kv.} \\ I_1 &= i_0'\ (0.928-0.028j)-55\ (0.010+0.974j). \\ &= i_0\ \ (.0928-0.028j)- \quad (0.5+53.5j)\ \text{amperes.} \end{aligned}$$

Hence, for: i_0 =	0	40	80	120	160 amperes
$E_1 = e_1' - j\,e_1'' =$	$50.9-1.5j$	$53.1-7.2j$	$55.3-12.9j$	$57.5-18.7j$	$59.7-24.4j$
$I_1 = i_1' - j\,i_1'' =$	$-0.5-53.5j$	$36.6-54.6j$	$73.7-55.7j$	$110.9-56.9j$	$140.-58.j$
hence, absolute:					
$e_1 = \sqrt{e_1'^2+e_1''^2} =$	50.9	53.6	56.8	60.5	64.5 kv.
$e_1\sqrt{3} =$	88.3	92.8	98.5	104.8	112.0 kv.
$i_1 = \sqrt{i_1'^2+i_1''^2}$	53.5	65.6	92.4	125.8	159.0 amp.
Input: $P_1 = e_1'\,i_1' + e_1''\,i_1'' =$	55	2330	4790	7430	10,250 kw.
Apparent input: $Q_1 = e_1\,i_1 =$	2720	3520	5260	7610	10,270 kva.
Output: $P_0 = e_0\,i_0 =$	0	2200	4400	6600	8,800 kw.
Power-factor: $\frac{P_1}{Q_1}$ =	2.0	66.3	91.1	97.6	99.8%
				lag	lead
Efficiency: $\frac{P_0}{P_1}$ =	0	94.4	91.8	85.8	88.8%

The possible error of the calculation is of the magnitude:

$$\frac{a^3}{6} = 0.00007, \text{ or } 0.007\%,$$

thus far beyond the accuracy of the numerical calculation.

Generator volts and amperes are plotted in Fig. 1.

B. Determine generator voltage, current and power-factor, required to deliver 95,000 volts at 90 per cent power-factor lag, and at 90 per cent power-factor lead.

$$\begin{aligned} e_0 &= 55 \\ i_0' &= 0.90\ i_0 \\ i_0'' &= \pm 0.44\ i_0 \end{aligned}$$

Thus:

$$E_1 = 55\ (0.928\ -\ 0..28j)+i_0\ (0.90\pm0.44j)\ (0.055\ -\ 0.143j)$$

$$= (50.9-1.5j)+i_0 \left\{\begin{matrix} 0.112-0.126j \\ 0.013-0.131j \end{matrix}\right\} \begin{matrix} \text{lag.} \\ \text{lead.} \end{matrix}$$

$$I_1 = i_0\ (0.90\pm0.44j)\ (0.928-0.028j)-55\ (0.10+0.974j)$$

$$= i_0 \left\{\begin{matrix} 0.847+0.383j \\ 0.823-0.433j \end{matrix}\right\} - (0.5+53.5j) \begin{matrix} \text{lag.} \\ \text{lead.} \end{matrix}$$

Hence, for: *Lag*:					
$i_0 =$	0	40	80	120	160 amperes
$I_0 = i_0' + j\, i_0'' =$	0	36+17.6*j*	72+35.2*j*	108+52.8*j*	144+70.4*j*
$E_1 = e_1' - j\, e_1'' =$	50.9−1.5*j*	55.4 − 6.5*j*	59.9 − 11.6*j*	64.3 − 16.6*j*	68.8 − 21.7*j*
$I_1 = i_1' - j\, e_1'' =$	− 0.5 − 53.5*j*	33.4 − 38.2*j*	67.3 − 22.9*j*	101.1 − 7.5*j*	134+7.8*j*
$e_1 = \sqrt{e_1'^2 + e_1''^2} =$	50.9	55.8	61.0	66.4	72.1 kv.
$e_1 \sqrt{3} =$	88.3	96.8	105.6	115.3	125.0
$i_1 = \sqrt{i_1'^2 + i_1''^2} =$	53.5	50.7	71.1	101.4	134.3 amp.
$P_1 = e_1'\, i_1' + e_1''\, i_1'' =$	55	2100	4310	6620	9060 kw.
$Q_1 = e_1\, i_1 =$	2720	2830	4340	6730	9690 kva.
$P_0 = e_0\, i_0' =$	0	1980	3960	5940	7920 kw.
Power-factor: $\frac{P_1}{Q_1} =$	2.0	74.3	99.3	98.4	93.5%
Efficiency: $\frac{P_0}{P_1} =$	0	94.3	91.9	89.7	87.4%

lead<——— ———>lag

Lead:					
$i_0 =$	0	40	80	120	160 amperes
$I_0 = i_1' - j\, i_0'' =$	0	36 − 17.6*j*	72 − 35.2*j*	108 − 52.8*j*	144 − 70.4*j*
$E_1 = e_1' - j\, e_1'' =$	50.9 − 1.5*j*	50.4 − 6.7*j*	49.9 − 12*j*	49.3 − 17.2*j*	48.8 − 22.5*j*
$I_1 = i_1' - j\, i_1'' =$	− 0.5 − 53.5*j*	32.4 − 70.8*j*	65.3 − 88.1*j*	98.3−105.5*j*	131.2 − 122.8*j*
$e_1 = \sqrt{e_1'^2 + e_1''^2} =$	50.9	50.9	51.3	52.2	53.7 kv.
$e_1 \sqrt{3} =$	88.3	88.3	88.9	90.5	93.1 kv.
$i_1 = \sqrt{i_1'^2 + i_1''^2} =$	53.5	77.9	109.7	144.2	179.7 amp.
$P_1 = e_1'\, i_1 + e_1'\, i_1'' =$	55	2110	4320	6650	9180 kw.
$Q_1 = e_1\, i_1 =$	2720	3960	5610	7520	9660 kva.
$P_0 = e_0\, i_0' =$	0	1980	3960	5940	7920 kw.
Power-factor: $\frac{P_1}{Q_1} =$	2.0	53.3	77.0	88.4	95.0%
Efficiency: $\frac{P_0}{P_1} =$	0	93.8	91.6	89.3	86.3%

Generator volts and amperes are plotted in Fig. 1.

C. Determine voltage, current, and power-factor of receiving circuit, at which maximum power is delivered from a generating station giving 120 amperes at 110,000 volts three phase.

110 kv. between lines gives $e_1 = 110 \div 3 = 63.6$ kv. per line.

Let:

p_1 = power-factor,
g_1 = reactive-factor at generator,

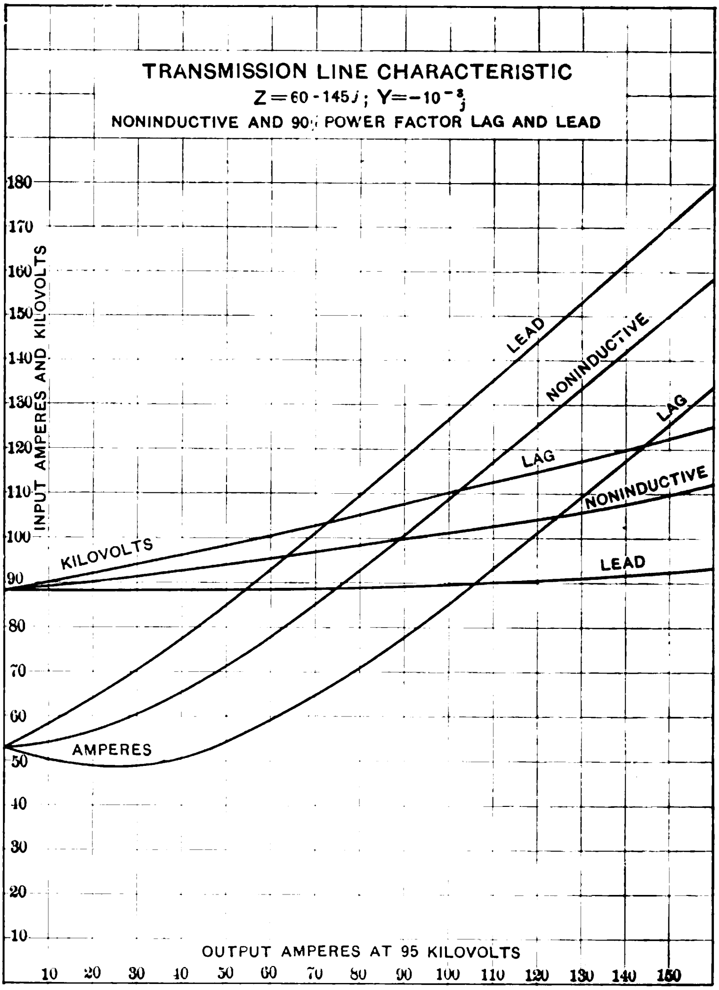


Fig. 1

it is:

$$\underset{\cdot}{I}_1 = i_1' + j\, i_1'' = i_1\,(p_1 + j\, g_1) = 120\,(p_1 + j\, g_1)$$

Hence, by equations (23):

$$\begin{aligned}
\underset{\cdot}{E}_0 &= 64.6\,(0.028\,j) - 120\,(p_1 + j\, g_1)\,(0.055 - 0.143j)\\
&= (59.9 - 1.9j) - (6.6 - 17.2j)\,(p_1 + j\, g_1)\\
\underset{\cdot}{I}_0 &= 120\,(p_1 + j\, g_1)\,(0.928 - 0.028j) - 64.6\,(-0.010 - 0.974j)\\
&= (111.4 - 3.4j)\,(p_1 + j\, g_1) + (0.6 + 62.9j)
\end{aligned}$$

Hence, for									
$q_1 =$	+0.5	+0.3	+0.2	+0.1	0	− 0.1	− 0.2	− 0.3	−0.5
$p_1 =$	0.87	0.95	0.98	0.99	1.00	0.99	0.98	0.95	0.87
$E_0 = e_0' + j e_0'' =$	$45.6+9.8j$	$48.4+12.4j$	$50+13.7j$	$51.7+14.4j$	$53.3+15.3j$	$55.1+15.8j$	$56.8+16.3j$	$56.8+16.4j$	$62.8+16.4j$
$I_0 = i_0' + j i_0'' =$	$99.4+116.6j$	$107.7+93.1$	$110.6+81.9j$	$111.7+70.6j$	$112+59.5j$	$111.1+48.4j$	$109.2+37.3j$	$105.7+26.3j$	$96.0+3.2j$
hence, absolute:									
$e_0 = \sqrt{e_0'^2 + e_0''^2} =$	46.6	50.0	51.8	53.7	55.5	57.3	59.1	61.0	64.9
$e_0 \sqrt{3} =$	80.7	86.6	89.7	93.0	96.3	99.2	102.3	105.5	112.3
$i_0 = \sqrt{i_0'^2 + i_0''^2} =$	153.3	142.4	137.6	132.2	126.8	121.2	115.4	109.0	96.1
$P_0 = e_0' i_0' + e_0'' i_0''$	5670	6380	6650	6800	6880	6900	6810	6640	6080
$P_1 = e_1 i_1 p_1 =$	6740	7360	7600	6700	7750	7700	7600	7360	6740
$Q_1 = e_1 i_1 =$	7750								
hence, efficiency:									
$\frac{P_0}{P_1} =$	84.1	86.7	87.5	88.3	88.8	89.6	90.1	90.7	90.2
$\frac{e_0''}{e_0'} = \tan E_0 =$	.215	.256	.274	.278	.287	.287	.287	.278	.261
$\frac{i_0''}{i_0'} = \tan I_0 =$	1.17	.865	.741	.633	.532	.436	.342	.249	.033
	12.2	14.4	15.3	15.8	16.0	16.0	16.0	15.8	14.8
	49.5	41.0	36.6	32.3	28.0	23.6	18.9	14.0	2.0
$- \measuredangle E_0$	37.3	26.6	21.3	16.5	12.0	7.6	+2.9	− 1.8	− 12.8
$p_0 = \cos\theta_0 =$	79.2	89.4	93.1	95.9	97.8	99.1	99.9	99.9	97.6
$q_0 = \sin\theta_0 =$	60.5	44.8	36.3	28.4	20.8	13.2	+5.1	− 3.1	− 22.2

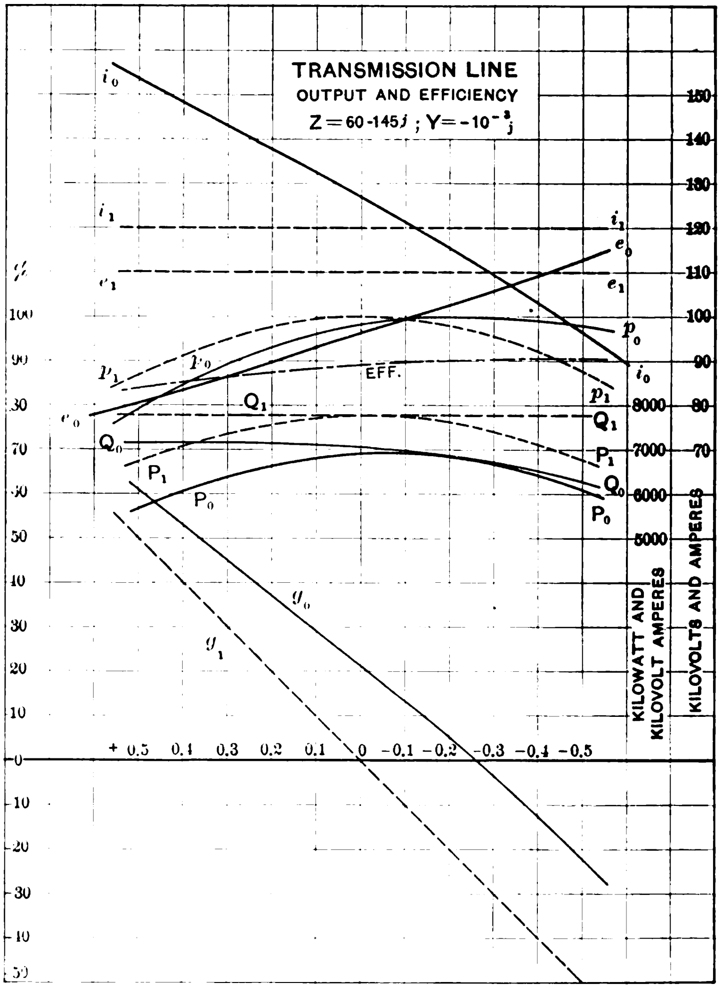


FIG. 2

Volts, amperes, efficiency, power-factor, and reactive-factor are plotted in Fig. 2, with the values at the receiving end in full lines, at the generator end in dotted lines, and the reactive-factors at the generator end of the line as abscissas.

DISCUSSION ON "ELECTRIC CONTROL FOR ROLLING-MILL MOTORS." "AUTOMATIC MOTOR CONTROL." "FUNCTION OF FLY-WHEELS IN CONNECTION WITH ELECTRICALLY OPERATED ROLLING MILLS." "POWER REQUIREMENTS FOR ROLLING HIGH CARBON STEEL OF SMALL SECTION." "ELECTRIC POWER PROBLEMS IN STEEL PLANTS." "ROLLING-MILL MOTORS." "ELECTRIC DRIVEN ROLLING MILLS." FRONTENAC, N. Y. JUNE 30, 1909.

(Subject to final revision for the Transactions)

D. B. Rushmore: The subject of steel-mill work is certainly as important as anything at hand just now in the way of electrical development, and the most important requirement of steel-mill work is reliability. It is unfortunate that steel mills will to some extent buy on prices, but they are outgrowing that, because price always means a sacrifice of engineering features. The value of the output is so great in comparison with that of the machines which are used in its production that I think it is a wrong policy to make any very great difference in the equipment due to a difference in price, assuming that several alternative schemes are presented; that is, putting all the manufacturers on the same basis, the ordinary factors of competition, it seems to me, should in these cases give way. In reality, the man who is to control this situation should be the engineer of the steel mill and not the purchasing agent, because all manufacturers are to a large extent interested together in the success of electricity as applied to steel-mill work. At the present time there is no phase of the electrical development of steel-mill work more important than the control apparatus, for the steel mills must electrify generally if they are going to compete with those who have already done so and the controlling apparatus must be perfected so that the output of the mill should not be interfered with.

Mr. Tschentscher has touched the edge of the subject of getting power from the waste gas, but whether burning the gas directly under gas engines or burning it under the furnaces, or utilizing it in connection with steam turbines, is the best means of using it is still an unsolved problem. The design of gas engines for blast-furnace gas, for large powers, is by some considered somewhat of an open question; for while it is easy to figure out the supposed thermodynamic efficiency and the actual cost of the power which one will get, yet the development is not on such a basis that that is all that needs to be considered. What the steel-mill man wants is the net return on the gas from the operation of the steel mill; one of the factors is the output, and any interruption to service goes heavily against the cost of this, and has to be considered in estimating the cost of power. The proprietors of steel mills say they can handle electrically driven mills better than steam driven mills, for the reason that the piece always goes through the roll at approximately the same speed and they are in better shape to start the succeeding movement. The reciprocating apparatus is practically doomed, it seems, with the possible exception of the gas engine, and that has a threatening successor in the gas turbine. The use of gas turbines and the possible use of gas through the furnace and for steam turbine work, would practically remove all reciprocating apparatus from the steel mill.

Mr. Specht has picked out, perhaps, the most interesting problem in steel mill work, the fly-wheel capacity for special service. Unfortunately, this particular determination is not always left to the motor manufacturer. It seems that steel mill men, realizing that it is difficult to maintain normal conditions continuously on roll trains, often specify motor capacity and fly-wheel capacity much in excess of that needed for normal operation.

On the other side, there has been of late a carefully performed series of experiments to determine the power required for rolling steel, and some very interesting results have been obtained in regard to the variation of this power with the temperature of the piece. That is one case to illustrate the point that there is necessarily in all this class of work a very large margin, because the factors which enter into it cannot all be determined with precision, and are susceptible of considerable variation.

Brent Wiley: The following formula offers a convenient method of calculating the fly-wheel capacity of a system, and for an average case the run of the fly-wheel is figured as two-thirds of the total weight and the spokes and hub one-third of the total weight.

$$\text{Wt.} = \frac{F\,s \times 2 \times 32.2}{B}$$

Wt. = weight in pounds.
$Fs.$ = foot-pound-seconds = h.p. × 550 × sec.
B = difference of velocity squared at high and low speed in feet per second at radius of gyration.

I understand that originally the automatic features in the Indian Steel Company's plant were incorporated in the motor-control apparatus and that later the system of control was changed somewhat; that is, to the extent of operating the controllers instead of automatically cutting in and out the resistances operating the motors with a permanent resistance.

K. A. Pauly: When the proposition for the rail-mill motors was being considered, the use of a small permanent resistance versus a variable resistance in the rotor circuit, to allow the fly-wheel to take the peaks, were discussed thoroughly; and it was finally decided that because of the ease of removing the automatic variable feature, that it would be better to install the automatic control. Tests made after the apparatus was installed indicated clearly the use of a permanent resistance to be preferable. However, the direct-current contactor (because of the high inductance of its operating coils and the lack of opportunity of raising the impressed potential sufficiently above the operating potential by the insertion of resistance in series with the solenoids) is necessarily more sluggish than the alternating-current contactor. Possibly with the alternating-current contactor, recently developed, which operates more rapidly, there may still be something in the automatic acceleration and retardation over a small range. However, as the control with permanent resistance operates satisfactorily, and eliminates one of the possible troublesome parts of the control equipment, the automatic feature should be, at least for the present, omitted entirely.

With reference to Mr. Specht's paper, it must be borne in mind in determining the capacity of a fly-wheel to meet any given cycle, that the fly-wheel is employed as a means of reducing the operating cost of rolling. There are, therefore, many factors which must be taken into consideration in determining the most economical fly-wheel capacity. Among the important ones which are frequently overlooked are:

1. The cost of power, the first cost of the generating station and of the rolling-mill motor.

As pointed out in the paper, by the use of the fly-wheel we reduce the capacity of the rolling-mill motor necessary for performing the work, and of the generating station supplying the power, but at the expense of efficiency. When the cost per unit of power and the cost per kilowatt of generating capacity are high the economical size of fly-wheel is greater than when these costs are low.

2. The capacity of the fly-wheel is affected by the overload capacity of the generating units. For example, the most economical weight of the fly-wheel is greater where power for rolling is supplied from gas-engine-driven generators (which because of the better economy of the engines near the maximum load frequently have little overload capacity) than when the power is from a turbine station the momentary overload capacity of which is very large, due to the immense fly-wheel energy of its discs.

3. The capacity of the fly-wheel is affected by the number of mills or motors driven from the same generating station and, therefore, the number of intermittent cycles, which are combined to form the generator load curve. As the number of mills increases the peaks of the station load curve decrease. Beyond a certain point, depending on the overload capacity of the generating station, the advantages of the fly-wheel are confined to the rolling-mill motor. and the fly-wheel capacity may be reduced to a minimum

A fourth advantage of the fly-wheel that is difficult to capitalize at present, is the increase in reliability and life of the rolling-mill motor resulting from the reduction in mechanical and electrical strains in the windings.

A great many advantages have been put forth in favor of the steam turbine as a generating unit for supplying power for rolling mills. I think, however, little consideration has been given to the possibility of increasing the efficiency of the rolling by the use of turbine-driven generators.

M. O. Dellplain: There is a matter which might be brought up at this time and one regarding which steel-mill engineers would probably all appreciate information, as it has to do with the only portion of the mill in which electricity has not as yet been positively accepted. I refer to the use of motor-driven air compressors for operating the hammer shop. The successful application of air for use in the hammer shop would mean practically the complete solution of the problem of the electrification of the steel mill.

Clark S. Lankton (by letter): Mr. Specht says that in motor-driven sheet mills the automatic control can not be used to advantage, that it would do more harm than good. I wish to take the ground that a proper control for induction motors driving sheet mills is a very much desired feature. The advantages of control do not make themselves felt in the way it was first intended they should; that is, to smoothe out the peaks. This is not practical because, as Mr. Specht says, the fluctuating load is too quick for the automatic feature to act. The control is practical, however, in that it affords a large amount of protection.

A sheet mill has from four to ten stands of rolls connected to the same shaft and each set of rolls is manned by a separate crew, each working independently of the other, hence the total load on the motor is made up of as many components as there are mills. Each unit requires power over and above its friction load, but a relatively short period of the total time; that is, the actual time that iron is being passed through the rolls is short, say one-eighth of the total time, or 3 hours out of 24.

The different crews have no relation to one another, and, with several mills operating, combination loads of almost any magnitude might result. A motor of gigantic proportions would be required to meet every possible combination of peak loads which occur, although the square-root of the mean-square load would not require so large a motor. The advantage of a large fly-wheel reserve is apparent.

It has been suggested that a permanent amount of external resistance be inserted in the circuit of the motor secondary in order to obtain slip enough to allow the utilization of the fly-wheel energy. By this method the motor would run with lessened efficiency, not only at times of heavy load, but also at times of medium and light loads, which is by far the greater part of the time. The efficiency could be improved by installing a larger motor which would allow of less of slip, but, on the other hand, it would have increased capacity and greater first cost.

It would not be so bad to sacrifice efficiency for a few seconds during a heavy jam, and, with proper control, it would be possible to hold the motor to the load until the load became excessive;

then to allow the motor to give way and receive aid from the wheel—thus the lower efficiency would be operative only occasionally and then for only a few seconds at a time. I have seen a sheet mill successfully operated in this way and no trouble from control for some period of time.

Let us give up trying to smooth out every fluctuation, but do not discard the control feature. Set the control to operate at a high load, however, and use it as a protection against the unusual peak rather than to level all peaks. If the source of supply is a little larger than the capacity of the mill, these smaller fluctuations will not be troublesome, and because of their frequency with the added number of mills the resulting load approaches a continuous load.

H. C. Specht: The amount of fly-wheel effect of an induction motor, with wound rotor particularly, is fixed mainly by the design itself, and it is very difficult to add more fly-wheel effect unless the additional weight is placed on a smaller radius, where it is not as effective. Further, it is not often desirable for mechanical and other reasons to put all the fly-wheel effect in the motor. Assuming, for instance, that a motor has to drive certain machinery, and a specific fly-wheel effect is desirable, also that at some later date the machinery driven by the motor is to be changed or the motor has to be used otherwise; under these circumstances the fly-wheel effect first placed in the rotor may be no longer the right one. Then the motor would have to be changed, and in such a case it would be more desirable to make the motor a normal design in the first place without particular reference to the required fly-wheel effect. Any additional necessary fly-wheel effect is then secured by coupling to a separate fly-wheel. A further advantage of this arrangement is that the motor is relieved of any sudden shocks.

The equations which I give for the torque curve have also been worked out by Mr. I. E. Hanssen in a similar way, and agree exactly with mine.

Chas. F. Scott: The problem of power generation which has been presented, the peculiar conditions of power supply through gas at the steel mill, the severe conditions of fluctuating load—all these bring severe and peculiar conditions which must be taken into consideration and treated in a broad way by the engineer who is handling them. It was said by one of the speakers that the electrical engineer in the steel mill is only 40 per cent an electrical engineer and 60 per cent a business man. I am rather inclined to think that some of the things classed as business in that position are properly engineering, engineering in the broader sense, as the engineer must take into consideration not merely the formulas on which his apparatus is based, not merely the electrical phases of his apparatus, but that larger engineering consideration which applies means to the accomplishment of results. This larger view also includes the mechanical conditions in which the various elements are controlled by the electrical apparatus, and the various operations in which the electrical apparatus simply plays a part. There are other considerations. He must be human, and must be able to handle the rather obtuse mill operators who do not like to do anything differently from what they have been accustomed to do it. All this emphasizes that the steel mill engineer must be a pretty large and progressive man.

The matter of power-factor was referred to. Power-factor has a rather disagreeable reputation, and when one finds it attached to anything, it is usually regarded as quite discreditable. Mr. Tschentscher takes pride in telling that he has been able to save $10,000 a year in wiping out this power-factor, and I take it this is a case where auxiliary machines are fully justified. They are installed at the end of the transmission line, so they relieve the line of carrying an extra amount of current. But, after all, has he accomplished something which is large and fundamental? He saves $10,000 a year on 7000 h.p. of motors' or something less than $1.50 a year per motor horse power. That is equivalent to the saving of $1.50 a year in the power supplied to the motor for each horse power rating. I do not know what the power is estimated as costing; it is probably fairly high for the rated horse power of the motor, because motors in the cement mill are called upon to do fairly continuous duty. If the power costs $15 per year, the saving would be about ten per cent on the power; that is, the power would cost $15 instead of $16.50. If the cost were $30 a year, it would be a saving of about five per cent, so that in this case the power-factor of the motor is a matter which would increase the cost of power by five per cent or ten per cent. If direct-current motors were used, and the power-factor avoided by discarding the induction motor, there would be new objectionable features introduced, such as the loss in transmission apparatus, synchronous converter, or motor-generator, as well as a higher first cost and attendance.

In applying electricity to steel mills the first thing that is usually thought of, the thing that has been given large consideration here to-day, is in the supply of power. The supply of power, considered in comparison with the total cost of production, is probably a relatively small factor, the larger matters being considerations of operation, of continuity of service, of applying the power effectively. If the motor can work more effectively—if, in conjunction with the mill which it operates, it can do better service, or produce a saving in labor, or more uniform or greater output—then these savings will far overbalance the saving in power, will far overbalance the fixed charges on the first cost of the motors. Consequently effective operation is a point of far more value than the others I have mentioned.

I have been interested in Mr. Friedlander's paper in the description of the operation of certain mills by motors, and in the number of points which be brings out showing the indirect advantages of the motor, not simply because it does what the engines already do or could do, with possibly a saving in the power cost, but also in doing things which the engine did not do and could not do. In his second paragraph he tells us that the rolling mill drive has taught us how to get the best relation among rotating masses, speed, time, and horse power. It has helped the roll designer to calibrate rolls in such a manner that the power characteristic for all the passes is uniform, thereby avoiding high power peaks, decreasing the size of the prime-mover, and reducing first cost and fuel consumption. The watt-hour meter warns the roller that bearings or rolls are becoming tight and hot, or that steel is causing excessive friction in the passes, often due to overfilling, cold steel, or faulty calibration, thereby guarding against damage to the rolls and bearings. The meter indicates that lower heat, greater elongation, and especially change of profile in different directions, increase the power required at the rolls much more rapidly than do chemical hardness, high tensile strength, or large draughts.

After analyzing the conditions in reciprocating engines for this work, we find that the characteristics of the electric motor are much better. A little further on he says that heavy reciprocating engines cannot run at such high speed, and must be connected to the rolls by means of gears, ropes or bolts. Again:

> To obtain accurate information as to the exact power requirements for rolling steel, indicator diagrams were taken on reciprocating engines doing similar work, but these in many instances were misleading. * * *. With the use of electric motors in place of reciprocating engines, the problem of reversing rolls becomes much simpler and better, in regard to manipulation, fuel consumption, and cost of maintenance.

Now, these are all indirect things, points of inherent superiority of the electric drive over the steam drive, points which show a reaction or interrelation between the motor and the mill, which indicate that the motor is going to have a vital effect upon mill work because it does what the engine cannot do.

John C. Reed: Have controllers ever been designed for obtaining dynamic braking in connection with an induction motor?

H. E. White: So far as I am aware, there is no method of applying current to the induction motor that will bring it to rest, without a tendency to start it in the opposite direction. In some installations now being made, current is being applied with reversed phases, and some means is used to shut off the reverse current when the motor stops.

In reference to Mr. Wiley's question concerning the automatic features of the control of large induction motors, Mr. Pauly has given the principal points. From the controller designer's standpoint it appears to be very desirable that the arrangement of the control be chosen so that a permanent resistance can be left in the motor circuit. It is a simple matter to arrange it so that the permanent resistance can be changed by changing the position of the master controller.

If automatic overload features are used, and a number of excessively heavy loads occur at short intervals, the speed has a tendency to be greatly reduced; if, however, resistance is left in permanently without automatic overload features, the torque will increase to the limit of the motor and the work will be carried through. I think that with the use of alternating-current contactors instead of direct current we would not have very much difference in action in either case. If the motor is running synchronously with all resistance cut out, the current will increase very greatly with a slight change in speed, but it is difficult to get automatic overload devices that will operate before the current shows an undesirably great increase.

I should have said no method of applying alternating current. The large induction motors at Gary are now equipped to apply direct current to the stators of the motors, and this will stop these motors and fly-wheels in a few minutes, when they might run unretarded for as many hours. I understood the question to apply to alternating current only.

In my experience with contactors for alternating current, which has recently been extensively increased, I find that under all the conditions of design with which I am familiar they permit of very quick closing. While I have no doubt that an oscillogram of the operating current would show some very curious things, yet the contactors I am familiar with always close practically instantaneously; it is easy to see that this must be so, for even on 25-cycle current the time between the minimum and the maximum current value is only in the nature of about one one-hundredth of a second.

A. M. Dudley: Mr. Parker asked about the relative desirability of having the entire amount of fly-wheel effect desired rotating at the same angular velocity as the motor, or connected to the motor by belting or gearing, and running at a higher speed. Mr. Specht, I believe, did not quite cover that point. Mr. Parker's statement is true, that there is no advantage in the one over the other, as far as the actual weight of the active material in the fly-wheel itself is concerned; that is to say, the same weight will have to be kept but disposed differently. It has been my experience, however, that when the extra weight is taken out of the motor structure and not carried on the motor spider, it is possible to build the entire motor somewhat lighter. It seems to me there might possibly be some advantage in that direction.

Mr. White said that he believed there was no method of employing dynamic braking in connection with the wound secondary motor and bringing it absolutely to rest. This holds good unless direct current is used in connection with the windings; that is, direct current is introduced into one member or the other, in which case the same effect is obtained as on a direct-current machine.

H. K. English (by letter): Mention is made of the fact that the time required to accelerate or decelerate a heavy fly-wheel must not be overlooked. This is especially true in plate-mill work, where it is often desirable to increase the rolling speed considerably after the first heavier passes are through. As an illustration, take the example used in the paper. Should it be decided to change at the end of the ninth pass, from 52 to 104 rev. per min. for the remaining 10 or 12 passes, the 120.000,000 lb-ft.[2] fly-wheel would obviously be out of the question on account of the time and energy required to accelerate it to 104 rev. per min.

Again, it is an advantage, where possible, to have in the fly-wheel enough stored energy to clear the rolls should the power fail, or should the motor, for any reason, become momentarily inoperative. Referring once more to the data sheet, pass No. 9, Fig. 3 represents some 11,700,000 ft. lb., while a 20.000,000 lb-ft.[2] fly-wheel running 52 rev. per min. has but 9,250,000 ft. lb. stored energy. Should the power fail just as the steel is entering for pass No. 9, the rolls would not be cleared, making it necessary to loosen the rolls, reverse the motor, and back out the steel. This consideration is of more importance in a rail mill with a number of motors in a train, and large quantities of steel, in different stages of completion, in the mill at one time.

I mention these two points to emphasize the fact that the choice of a fly-wheel for any given installation will be governed, more by an all-round practical consideration of the case in hand than by any mere efficiency calculations.

There has just been completed a series of tests on an electrically driven rail mill which has recently been put in operation. and it has been very gratifying to see how closely the test values check the original calculations both as to power required for the several passes, and as to motor performance. In view of this fact, and the successful record this mill is making, it would seem that Mr. Specht is scarcely justified in assuming that careful study has not been given these first installations.

Arthur C. Eastwood (by letter): I believe attention should be directed to the conditions under which controllers must operate in a steel mill. I refer to the controllers described by Mr. White and Mr. Henderson in which a separate series relay is associated with each contactor in a controller, the closure of each successive contactor being governed by the current flowing through the motor, and each series relay being susceptible of individual adjustment.

In steel mills I believe it is common practice when records are in view to doctor the controller relays with bolts, nuts, and wrenches. In other words, under mill conditions a controller designed automatically to limit the current input of a motor may, in a few seconds, lose all semblance of current-limit acceleration, the cutting out of the resistance being governed solely by the time element of the contactors or magnetic switches. Further, the larger the number of adjustments provided, the greater the chance for maladjustment where uneducated and electrically unskilled rollers, table men, shear men, millwrights, etc., have access to the controller, and where the adjustments are purely mechanical, consisting in weighting a plunger or tightening a spring. Even in the hands of a skilled electrician, to secure accurate adjustment of a controller having a relay on each switch, a recording ammeter is almost a necessity.

As to the advantage found by Mr. Henderson for the multiple relay system of acceleration; that is, the ability so to adjust the relays as to interpret the commutation curve of a motor— it is conceivable that this is an advantage under some conditions but not one which is likely to appear in a steel mill. A steel-mill engineer would hardly install a motor so near the limits of commutation that special provisions would be required to help it out, and if such a motor were inadvertantly installed it should be very promptly torn out and a motor installed better suited to conditions.

There is another system of automatic relay acceleration not described by either Mr. White or Mr. Henderson, which was specifically designed to meet conditions as they exist in steel-mill service, and it is extensively used in many of the largest steel works in the country. In this system only a single accelerating relay is employed. Hence there is but one adjustment; and accurate adjustment as to maximum accelerating current can be determined by the use of an ordinary indicating ammeter. The relay has a single winding of coarse wire, controls only a single pair of contacts, and in service is ordinarily enclosed in an iron box which can only be opened by a key in the form of a special horseshoe magnet with which only those properly qualified to make the adjustment are provided. This prevents tampering with the adjustment on the part of those not properly equipped to do so.

Further, the adjustment for varying the maximum accelerating current is electrical and not mechanical. Consequently an unskilled worker who would not hesitate to hang a weight on the ordinary form of relay is very likely to keep hands off, since he will hesitate to tamper with electrical connections.

The adjustment is obtained by varying the portion of the total motor current which passes through the winding of the relay, and is accomplished by shunting the winding of the relay. The constants of the relay itself remain fixed. It will always lift its plunger when a certain definite current flows through its winding. Assuming this current to be 50 amperes and the desired maximum motor current to be 100 amperes, the relay will be so shunted that one-half of the motor current will pass through its windings. If the desired maximum motor current be 200 amperes, the shunt will be so adjusted that one-quarter of the total motor current will pass through the winding of the relay.

This method of shunting the winding of the relay not only provides means for adjusting the maximum accelerating current in case of a given motor and controller, but also permits of adapting a standard relay for use with motors varying widely in capacity. In an equipment installed in one of the large steel works of the country, embodying some 65 automatic magnetic controllers for motors varying in size form 25 to 250 h.p. duplicate relays were used in all of the controllers, the adjustable shunt in each instance adapting the relay to operate at the required maximum motor current.

A diagram of connections of this system of automatic acceleration is shown in Fig. 1, in connection with a reversing controller for a series-wound motor.

A is the armature and *F* the field winding of the motor.

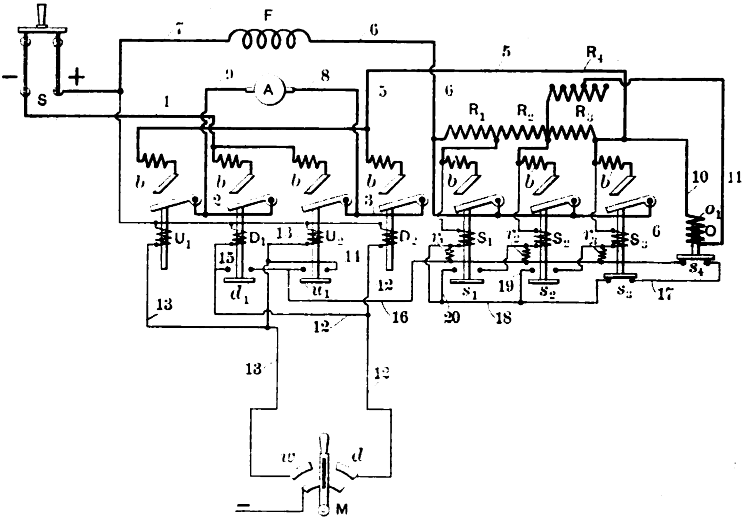
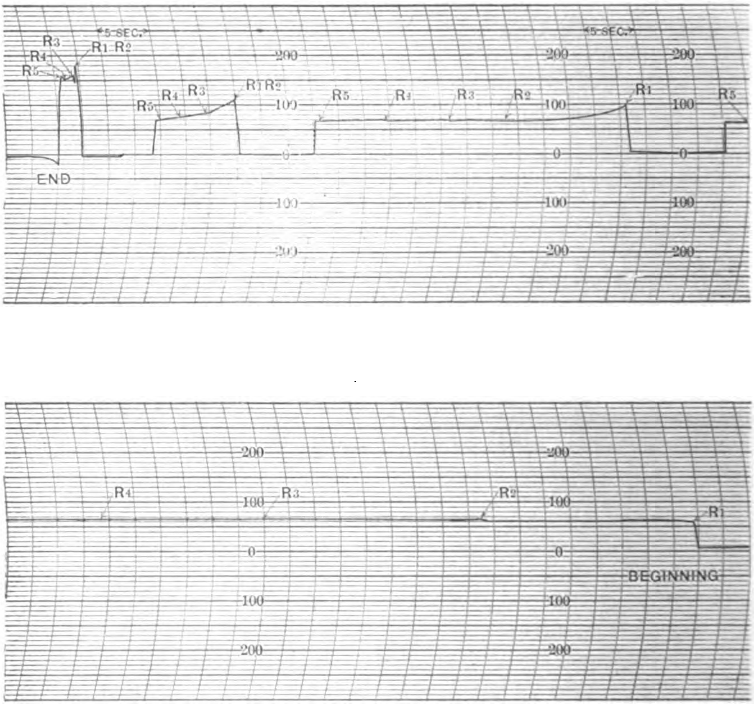


FIG. 1—Automatic accelerating controller

*R*1, *R*2, *R*3, and *R*4 are sections of resistance. *D*1 and *D*2 are reversing switches which give one direction of rotation, while switches *U*1 and *U*2 give the reverse direction of rotation. *S*1, *S*2, and *S*3 are magnetic switches controlling the sections of resistance *R*1, *R*2 and *R*3. *M* is the master controller through the operation of which the motor is started, stopped, and reversed. *O* is the accelerating relay which governs the closure of the resistance controlling switches *S*1, *S*2, and *S*3. *R*3 is an adjustable resistance which shunts the winding of the relay *O*. It will be seen that the main current flows from positive through the field *F*, the resistances *R*1 and *R*2 where it divides, a part flowing through the resistance *R*3, the wire 5, the reversing switches, and armature of the motor to negative, and the remainder flowing through the adjustable resistance *R*4 and the winding of the relay *O* to the wire 5 where it joins the other path. Obviously, the portion of the motor current which flows through the winding of the relay may be adjusted by altering the relative resistance of the two paths. It will be noted that resistances *r*1, *r*2, and *r*3 are associated with the windings of the switches *S*1, *S*2, and *S*3. These resistances are so proportioned that when in circuit with the winding of a switch-operating magnet they



ACCELERATION CURVES OF 25 H.P. 220 VOLT SERIES MOTOR WITH AUTOMATIC CURRENT-LIMIT CONTROLLER.

FIG. 2

will not permit sufficient current to flow to cause the switch to close, but will permit sufficient to flow to hold the switch closed after its plunger has been raised. The function of the contacts of the relay *O* is to control the resistances *r*1, *r*2, and *r*3. When the plunger of the relay is down, these resistances are short-circuited; when the plunger of the relay rises, these resistances are cut into circuit with the windings of the switch-operating magnet with which they are associated.

Assuming that the switch *S*-1 has closed, and in closing has produced a current value which causes the relay *O* to lift, the winding of switch *S*2 then receives current through the resistance *r*2 which, as previously mentioned, will not permit sufficient current to flow to cause the switch to close. It should be noted, however, that a small current flows through the winding of the switch which is about to close, thus partly building up the magnetism of its closing magnet and leaving the switch prepared to close promptly. This largely eliminates the time element of the successive switches in closing. When the motor has accelerated, thus reducing the current flowing through its windings to the proper point, the relay drops, thus short-circuiting the resistance *r*2 and permitting the switch *S*2 to close. Switch *S*3 is controlled in a similar manner.

The relay *O* is provided with but a single pair of contacts, and only a single electrical interlock is associated with the control circuit of each switch.

The curves shown in Fig. 2 were taken with a recording ammeter, and illustrate the acceleration of a 25-h.p. 220-volt series motor in which the maximum accelerating current, and hence the time of acceleration, has been varied by varying the resistance of the shunt round the accelerating relay, as above described. These curves illustrate the wide range of adjustment which may be secured in the total time of acceleration, showing as they do that the period of acceleration may be varied from 6.5 sec. to less than 2 sec. the accelerating current in the two cases being respectively 60 to 65 amperes and 160 to 165 amperes. These curves also illustrate the sensitiveness of the accelerating relay, showing that it will raise and drop its plunger with current variations of less than 5 amperes.

As to the Hulett unloader, which was described by Mr. Henderson as offering particular advantages for automatic control, the writer can speak with some authority as he designed and installed the controlling equipment for the first electrically operated Hulett unloaders in 1902 and 1903. On the first Hulett unloaders (installed at Conneaut, O.) the machines were driven throughout by steam and hydraulic power. The next machines (the first three installed on the Lackawanna Steel Company docks at Buffalo, N. Y.) were driven electrically with the exception of the bucket-closing and rotating mechanisms, which were operated by means of hydraulic cylinders. This necessitated mounting on each machine a motor-driven pressure pump operating at 1000 lb. pressure, a motor-driven air compressor, an air-hydraulic accumulator, and an elaborate system of high-pressure piping, swivels, valves, etc., which was a prolific source of trouble not only in itself but on account of damage to electrical apparatus which occurred through frequent leaks in the hydraulic system.

Hydraulic power was selected for the operation of the bucket because of the absolute necessity of limiting the torque or pull which occurred in closing and rotating the bucket. The bucket of the unloader is suspended from a structural leg some

40 ft. in length, as illustrated in Fig. 3, which shows the bucket of one of these machines in the hold of the steamer " Wolvin ". In scraping ore from between hatches, or in case the bucket should entrain more ore than it could hold, or in case the bucket should foul a stanchion or other obstruction, obviously the torque or pull must be limited, as the bucket has a leverage of some 40 ft. on the frame of the machine, and a wreck would result if a definite maximum pull were exceeded. An electric motor with its ability to increase its torque to perhaps ten times full-load value before stalling appeared altogether unsuited to the purpose.

After experimenting with a number of other schemes, a form of controller was devised by the writer which gave to the operation of a motor substantially the characteristics of a hydraulic cylinder. In this controller a series relay was introduced, which weighed the load and when a given normal current was exceeded automatically, cut resistance into the motor circuit, thus limiting the current, and consequently the torque, to a safe maximum value. The arrangement was such that current would not be cut off from the motor when an overload occurred, but the current would be automatically limited and the current limiting resistance would be automatically cut out when the load was relieved. This arrangement successfully displaced the hydraulic

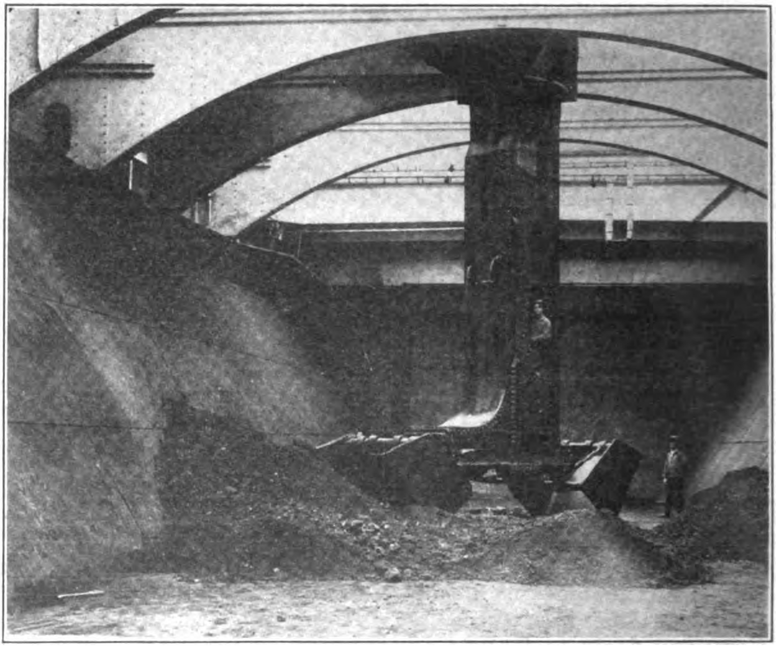


FIG. 3—Bucket leg of an ore unloader working in the hold of a steamer

cylinder and all subsequent Hulett unloaders have been similarly equipped. The Hulett unloaders on the docks of the Indiana Steel Company at Gary are equipped in this way, and are also equipped throughout with the system of current-limit acceleration above described.

Arthur Simon (by letter): Mr. Specht states that the automatic regulation of resistance in the secondary circuit of the slip-ring type of motor is not desirable on account of the sluggishness of the controlling apparatus, and he therefore restricts himself to the calculations of a slip-ring type motor with a fixed resistance and a fly-wheel. This method of operation is undoubtedly the simplest, but by no means the most economical. Mr. Specht agrees that theoretically the variable resistance method with a lighter fly-wheel would be preferable, but the writer is not convinced that it will be impossible to produce a controller which will follow quickly the changes in load on the motor.

As far as the writer is aware, the controllers which were designed to accomplish the automatic regulation of the secondary resistance were all influenced primarily by a current relay connected in the primary circuit of the motor. Furthermore, most of these controllers, or all of them, were of the pilot-motor type. In other words, there were several elements, which, with regard to the cycle of operation, were connected in series. The ultimate result was obtained only after the successive operation of all parts, which necessarily must consume considerable time. The writer is satisfied that it would be possible to connect proper relays in the secondary circuit of the motor. As the secondary current is the first quantity which is unfluenced by a change in speed, that is, the change in load, it is only logical to accomplish the control by means of a relay in the secondary circuit. This relay should influence directly contactors which control secondary resistance, and this method will give entirely satisfactory results as far as the speed of response is concerned, and, furthermore, be still, more desirable for other reasons, which will be discussed in the following:

Mr. White says that the 6000-h.p. motors at Gary are controlled by a pilot motor which is influenced by a current relay. A diagram of this control scheme was published in the "*General Electric Review*", and I note that the current relays are connected in the primary circuit. For the same reasons as stated above, these relays should be connected in the secondary circuit of the motor, and it is obvious that the scheme as shown in his Fig. 1 is preferable to the pilot-motor control. • Fig. 2 shows a double panel of this type. With the pilot-motor control the entire operation of the motor, and with it the operation of the plant, depends upon the pilot motor and the current relays controlling same. The failure of any one part will shut down the motor entirely, while with the control scheme shown in the diagram all parts are interchangeable and the failure of one element does not necessitate the shutting down of the entire plant for repairs, but merely the short-circuiting of this element while the motor can then operate with a reduced number of accelerating speeds, and it is still possible to keep the mill running while repairs on the part which is in trouble are being made. This control scheme also reduces the time element necessary for the action of the automatic slip regulation. If such automatic slip regulation in connection with a flywheel is desired, it will of course be necessary to change the connections of the relays somewhat, for instance, as suggested by Fig. 3.

Mr. White further states that the current relay control is undesirable for squirrel-cage motors started with potential starters. The writer cannot share this opinion and submits, herewith, in Fig. 4 a connection diagram, and in Fig. 5 a self-starter for squirrel-cage motors controlled by current relays. The objection to the constant-time-element control is that the motor is switched from the starting to the running tap of the transformer at a variable speed, which causes considerable variation in the surges on the line. Suppose that the motor-speed at which same is connected to full line voltage was 10 per cent below normal and the normal slip of the motor was 4 per cent, in this case the momentary current inrush would be 250 per cent of normal. Such slight variations in the speed when switching over are entirely possible with the constant-time-element control, while it is possible to set current-relay controllers very closely, say, within at least 10 per cent, which will entirely avoid the danger of momentary overload on the line to which the motor is connected, or the tripping of the circuit-breaker during starting.

A paper to be presented at the 241st meeting of the American Institute of Electrical Engineers, New York, December 16, 1909.

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(*Subject to final revision for the Transactions.*)

COMMENTS ON DEVELOPMENT AND OPERATION OF HYDROELECTRIC PLANTS

BY HENRY L. DOHERTY

INTRODUCTION

The object of this paper is to call attention to certain features of hydroelectric work deserving of more general or more careful consideration than they have had heretofore.

The writer is so situated that extended treatment at this time is impossible. If suggestions of value can be made, even though the treatment is incomplete, sufficient interest may be aroused to prompt such effort on the part of others as will carry these suggestions to a successful conclusion.

Work of value on this broad subject of hydroelectric enterprises can be done by the Institute which will result to the benefit of not only our members, but to the public as well. The writer will attempt to point out such work as, in his judgment, can be carried on to advantage.

THE VALUE OF WATER-POWER SECURITIES

There is probably no other class of securities which deserves so well the support of the public as those issued by companies owning and operating successful water power properties, and having a permanent and relatively non-competitive market.

Except for the possibility of further development in heat engines which will materially increase their commercial efficiency, thus tending to reduce the cost of power from fuel, all of our water power plants will tend to grow more and more valuable, as it is improbable that fuel will ever sell at a lesser cost, and more than probable that the cost will gradually increase. The reduction in first cost of heat engines, the increase of fuel economy, and the decrease in cost of repairs, are the only factors which will tend to lessen the market value of power from hydroelectric plants.

Almost every other class of industrial or investment property is apt to depreciate at a much greater rate, and be subjected to greater seen and unforeseen risks. For instance, business enterprises based on patents become less valuable as the patents expire; substitutes for manufactured commodities can often be found, or there may be developed other methods of manufacture which will prove more economical. As an exaggerated example, coal mining operations might be cited; the more coal is sold, the less the coal company has left for sale, unless new property is constantly purchased.

Compared with almost every other class of investment, a water power plant is far preferable. The source of supply is, in the main, perpetual, although in some instances somewhat modified by timber operations and changes in meterological conditions. Such modifications are, on the whole, more than offset by the possibilities of further power or irrigation developments which will provide reservoir capacity and make useful flood waters which have heretofore been unavailable for power.

THE RELATION OF WATER POWER DEVELOPMENT TO THE CONSERVATION OF OUR NATURAL RESOURCES

Probably the greatest stroke of statesmanship of the last national administration was the interest aroused in the conservation of our natural resources. Unfortunately, the efforts of the administration were either largely misdirected or very generally misunderstood in regard to water powers.

Immense amounts of power are daily going to waste. The tendency of the Federal Government, and of many of the state governments, seems to be directed toward obstructing rather than encouraging the development of water powers. This Institute can do valuable work in educating the public as to the restrictions which should be made and the encouragement which should be given to enterprises of this character.

The most pressing need in the matter of the conservation of our natural resources lies in the direction of conserving our various sources of fuel supply. Every undeveloped water power means a constant unnecessary fuel consumption.

Government, both state and national, should remove as far as possible every unnecessary obstacle to water power development. Rights of eminent domain should be given universally to water power projects. Encouragement, and perhaps direction, should be given which will insure the development of the greatest possible portion of the total energy available from our streams. Unintelligent engineering, or hampered finances, may result in stream developments which permanently limit the power production to a small fraction only of the total power which the stream might have been made to produce. For this reason, intelligent planning and engineering will play a most important part in the future history of the conservation of our natural resources.

COLLATERAL ENTERPRISES

Combination projects for both irrigation and power can often be made highly profitable where commercial success for either project alone would be impossible. It is therefore necessary that the engineer who has the responsibility of determining the value of prospective power developments should be proficient in the engineering of irrigation—and it is probably impossible fully to cover the field of hydroelectric engineering without knowing all of the essential details of irrigation engineering as well. This opens up to this Institute a necessary field of work which even now seems somewhat strange and a few years ago would have been entirely remote. Power and irrigation projects, wherein the power must be generated at one point and transmitted to another point and there provide irrigation by means of pumping, is alone worth serious consideration. As interruptions to supply due to long transmission lines are of relatively less importance in such service, it is possible to lessen the transmission investment and operate at distances which would be prohibitive for some other classes of work.

The present state of the art in electrochemical processes is a factor which makes possible the profitable development of many water powers. Still further developments along electrochemical lines may add materially to the value of water power projects which now have no available market. Special attention should be paid to processes which do not require a continuous supply of current, thus permitting the utilization of power from water which would otherwise run to waste.

THE UNFAVORABLE FEATURES OF WATER POWER ENTERPRISES AND THEIR OPERATION

Were we to assume that there is no risk in the development of water power projects, and that their operation has proved universally satisfactory, we should simply retard the correction of some of the difficulties which have been encountered. We have learned by experience that the cost of development often proves excessive and far beyond the estimates made by engineers enjoying good reputations. We have found that frequently the power expected has not been realized. We have found that transmission lines will not yield that reliability of service which can be secured from a steam plant generating at the point where the power is utilized.

Failure to realize expectations in regard to, cost of development, amount of power to be sold, existence of market (or of market at the price anticipated) and reliable service, has played an important part in the retardation of development of water power projects. The treatment of any one of these disappointing features would alone furnish subject-matter for at least one, and perhaps many more papers. It is unfortunate that mistakes have been made and that anticipations have not always been realized. If, however, we are to learn by experience, then the broadest possible discussion of these subjects is to be desired. It would contribute much to the ease of developing the now unused water powers if these difficulties could be overcome, or if the public could be made to understand the degree of risk and the cause for the existence of the risk.

Generally speaking, there is no more reason why anticipations should not be realized in water power enterprises than in other enterprises. if the proper amount of investigation and preliminary work is done. Unfortunately, however, the engineering investigation to determine the cost of a hydroelectric power proposition, and the exact amount of power available, is often a very expensive matter.

Accurate determination of the power available can be made only from complete data, and such data are obtainable only as the result of measurements extending over a term of many years. Our water power projects are exploited on everything from prospectuses based on the most complete data for determining every feature of the available power, up to and including the prospectus based on absolutely no reliable data.

Bankers, underwriters, and investors have formulated various rules regarding water power propositions. One prominent banker gave me this rule:

> We will not consider a water power project unless, after doubling the cost, cutting the available power in two, and reducing the market price by 40 per cent it will still show interest on the bonds necessary to issue.

This was spoken more or less in jest, but it and many similar statements warrant the belief that except among professional engineers the same, or similar, fixed and arbitrary rules for determining the merits of new projects are apt to be used by all classes of people who are to furnish the money for their development.

There is no reason why water power projects, with reliable stream gaugings covering a number of years, cannot be estimated, as to cost of construction and earnings, to a degree of accuracy closely approaching that which now pertains to the construction and earnings of modern office buildings, or similar enterprises.

If fixed additions to cost and fixed discounts from earnings are to be applied to water power projects, then we are apt to have the condition that only the poorer projects will be developed. The less known about an undeveloped water power the more readily can an attractive prospectus be written, leaving more than ample margin for any arbitrary deduction; while complete knowledge based on a thorough, honest, and intelligent investigation bring the promised earnings to a point which would not permit of further arbitrary deduction—nor, in truth, is further deduction needed.

After a proper examination has been made of a proposed water power plant, where the behavior of the stream is a matter of reliable record for several years, an enterprise of this character can safely be undertaken on a very narrow margin of profit. If, however, the investing public are offered a proposition for which a return of 10 per cent is estimated by conservative operators, based on careful and complete investigation, while other operators offer investment in a project for which they promise 40 per cent, the 10 per cent proposition is apt to go begging, even though it be well known that the source of the 40 per cent proposition is not of a character to warrant the investment of real money.

A confused condition exists in the popular mind in regard to the marketing of power. The inability of the public to understand this matter has been a great obstacle in the development of power propositions—and in this matter the electrical engineering fraternity has been more or less to blame. Cost of power is sometimes figured and stated on a kilowatt-hour basis, and at other times on the basis of peak load, or what might be termed a capacity basis. Without knowledge of load-factor, or simultaneous demand-factor, figures stated in these different ways may prove so misleading as to bring about expectations of returns varying all the way from $8 to $300 per horse power of station capacity. This confusion has played no small part in the mistakes which have been made; and these mistakes have caused the investing public to mistrust their ability to make correct deductions.

The problem of reliable service from long transmission lines is much further from solution than all of the other problems that have done so much to contribute obstacles to rapid development. Good engineering talent and other proper precautions will insure that the cost of construction shall be no greater than that promised. We can also accurately determine the available power, and can insure ourselves against disappointments in market. The best of engineering talent does not seem, however, able to promise for a transmission line the same continuity of operation that can be secured from a steam plant located at the point where the power is to be used, and this introduces many serious obstacles to the development of our water power projects. The importance of continuity of service varies in degree with almost every customer served. To some industries a mishap which causes even a fall in voltage or a change in frequency may be a serious matter.

MATTERS WORTHY OF DETAILED CONSIDERATION

In my observation and direct connection with water power propositions there have arisen many matters that deserve further thought and consideration by the engineers who are brought in contact with water power work, not only for their own benefit, but also for the education of the investing public and the power purchasing public. Some of these are as follows:

1. Methods to insure against interruptions or to lessen the harmful effect of interruptions.
2. Equipment to insure against interruptions or to lessen the harmful effect of interruptions.
3. Penalties for interruptions of service or insurance against interruptions.
4. Methods of charging.

5. Classes of service which can be advantageously supplied.
6. How to develop the market selected.
7. How to figure the amount of power it would pay to develop.
8. Calculations on depreciation.
9. Methods to determine the accuracy of engineers' estimates.

1. *Methods to insure against interruptions or to lessen the harmful effect of interruptions.* As previously stated, interruptions vary in seriousness with each class of consumers. To some even a long shutdown is relatively unimportant, while to others the slightest variation in frequency or voltage may prove highly objectionable.

With reliable reverse circuit-breakers, the tying in of several hydroelectric plants offered some insurance against interruptions.

If central-station companies are to be supplied, it might sometimes be commercially practicable, where the reachable market greatly exceeds the capacity of the plant, to run the transmission lines to several central stations, with the idea that no one of the stations will attempt to take more than a portion of its base load, and will always have some steam apparatus in operation, the capacity of which can be quickly increased to take care of any interruption of service from the hydroelectric plant.

In one case, arrangements were made several years ago to install a large steam turbine in connection with a relatively small water power plant, the generator of the steam turbine being designed to run as a motor while the vacuum on the turbine blades was maintained to reduce the windage loss, with the governor of the turbine so arranged that the slightest reduction in speed would cause the steam valves to open and the turbine immediately to pick up the load.

In a recent power negotiation, where the supply was to be furnished from two hydroelectric plants, it was suggested that one of these plants be run in the manner outlined above for the steam turbine; namely, that the generator should be run as a motor, and the water-wheel governor should be arranged to open up and drive the turbine if the speed fell off perceptibly.

In these cases the steam turbine, or water turbine, could be driven with a small amount of steam, or water, and the fields of the generator magnetized so that the load would be promptly picked up in case of interruption to service. This latter method, however, would be relatively less economical than to drive electrically, using steam or water only when service from the unit was demanded.

2. *Equipment to insure against interruptions or to lessen the harmful effect of interruptions.* It is customary on all important transmission lines to use either two circuits on the same pole-line or two circuits each on its own pole-line. The latter plan is far preferable.

Perhaps greatly added reliability could be secured by the use of extra conductors on each pole-line, with effective switching apparatus that would enable the extra conductor to be brought into use as quickly as possible.

The use of storage batteries is the first thing that occurs to one as a protection against interruptions, but their high investment cost and high cost of maintenance make them practically prohibitive when used purely to prevent interruptions of service.

Gas engines would be almost ideal, but the high investment charges make them practically impossible. They, however, have been adopted in one or more instances. A gas engine can be put into operation with marvelous rapidity, the time required being fixed by the time the electrical generator can be energized. Gas storage can be provided at a cost of approximately $50 per 1000 cu. ft., with no operating stand-by loss. This means an investment of about $400 per 1,000,000 B.t.u.'s for producer gas, about $80 per 1,000,000 B.t.u.'s for coal gas, and less than $70 per 1,000,000 B.t.u.'s for California oil gas.

Where producers are used, if the fires in the producers are maintained in proper condition, no storage capacity is needed; and perhaps no other similar class of apparatus can be run with such a small stand-by operating charge as a gas producer.

Unfortunately, however, a gas-engine power station represents such a high first cost that, in spite of the higher efficiency of the gas engine and the lower stand-by losses of the gas-generating apparatus, the commercial cost for purely relay service is higher than for steam equipment. If provision must be made for protection to service, a modern steam equipment offers about the lowest commercial cost.

This brings up several interesting points. The boilers chosen should be able to have their fires withdrawn without causing leaks, and boilers should be chosen having the least stand-by loss in relation to their maximum capacity. This means a boiler of either very high capacity or very low radiation and ventilation losses. Ordinarily we choose the boilers having the least consumption of fuel at full load, but for relay service we want the boiler having the least consumption of fuel at no load.

For wisdom in choice of boilers we need to know the efficiency from no load to maximum load, but the writer does not remember ever seeing an efficiency curve on boilers showing their economy from no load to full load. A slight increase in maximum capacity is of extreme importance for this class of work. It is unreasonable to suppose that with all the different makes of boilers now in use they all have anything like the same absolute capacity—and it is more than probable that the limit of capacity is determined by different features in different boilers. It is not likely that any very comprehensive determinations have ever been made on commercially economical, or ultimate, capacity of different types of boilers.

It is the writer's opinion that for this class of service the internally fired boiler deserves careful consideration, but perhaps only in a modified form. This boiler should show not only a small radiation loss, but ability to maintain tightness against unnecessary ventilation when run on bank, which is apt to be an important feature after the boilers have been in operation for some time.

This type of boiler, however, would be apt to be limited before other limiting features were reached by the lack of flue-gas conductivity of its fire tubes, which could be compensated for by a high draft pressure, but better compensated for by a modification in design.

If boilers are not to be run on bank, but are to be fired up if an interruption occurs, the methods to be used for quickly starting the boilers are of great importance.

The use of oil for fuel probably insures the greatest speed in starting up, but this fuel is often prohibitively expensive. It is, however, possible to use oil simply as an auxiliary in the starting of the boilers and then substitute coal, either hand-fired or machine-fired.

The writer does not remember ever having seen the suggestion made that powdered-coal firing be used for this class of work. Powdered fuel is almost the equivalent of oil or gas, and is ideal for the class of service under consideration. It probably costs more to powder fuel than to burn it, as received, with machine stoking; but for relay service, while the operating cost per ton of coal handled would be more, the investment charge would probably be far less; and a great gain would be made in the speed of starting as compared with ordinary coal fires, and a much greater economy of labor could be secured.

In the choice of steam engines the steam turbine would seem to be the only one worth consideration. The total first cost of steam turbines, including building, foundations, etc., should, alone, be enough to warrant their adoption; and if it were decided to turn these engines over idle, but with the fields of the generators magnetized, the steam consumption should prove materially less than for any other type.

3. *Penalties for interruptions of service or insurance against interruptions.* In a recent negotiation for the purchase and supply of power between a central-station company and a hydroelectric supply company, the question of continuity of service was given serious and detailed consideration. Various engineers were consulted and numerous suggestions were made.

The central-station company was not desirous of collecting any penalties, but insisted that they should have service of such degree of reliability that no serious damage should result, from such interruptions as might occur, to the business they then held, and that would enable the same rapid development of the business as then obtained to be continued.

It was concluded that any interruption, regardless of the length of such interruption, was harmful, and that the longer this interruption continued the more serious it became. It was also decided that one or more interruptions to the service immediately following the first interruption would prove more disastrous than if these interruptions were evenly distributed throughout the year.

As insurance against excessive interruption was being sought, and as the only insurance possible was that to be obtained through operation of the steam plant, it was decided that insurance should be obtained by running the steam plant (fully energized and ready to instantly take the load in case of interruption to the hydroelectric service) at such times and for such lengths of time at a stretch as might be necessary to insure against interruptions coming oftener than at certain intervals. For example, to take an extreme case of the simplest form, suppose it had been decided that no interruptions of any kind whatsoever were permissible more than twice in any twelve months. Then after any interruption the steam plant would be run for six months, ready to take the load at any time in case of failure of the hydroelectric supply. This would insure only two interruptions per year; for if another interruption occurred after the end of the six months, the steam plant would be run another six months, thus completing the year with only two interruptions.

It may seem curious, at first thought, to insure continuity of service, or, rather, to guard against more than a certain amount of interruption, by running the steam plant *after* an interruption. But, as interruptions cannot be foreseen, it is plain that the course outlined is the only one possible to accomplish the end aimed at with the least expense; that is, without running the steam plant continuously.

The above assumes that a steam plant is never subject to failure. But failures will occur at times in the most carefully operated steam plants, and this fact was taken into account by the allowance mentioned later.

The above also assumes that all interruptions, of whatever length, are equally disastrous, and that interruptions to all kinds of service, residence, business, and power, are equally disadvantageous. But as this is not the case, allowance was made for both the length of interruption and the damage to different kinds of service, as will be seen in what follows.

The load of the central station was divided arbitrarily into two classes, which we will call class *A* and class *B*. The power and the business district load together were considered as class *A* business, requiring the greater insurance against interruption. The residence load was considered as class *B* business.

The central-station company demanded that the length of time which the steam plant should be run after any given interruption should be fixed with reference to the duration of interruption and to the number of interruptions which had occurred during the year preceding and up to and including the interruption in question.

If the interruption in question was the first during said year, then the steam plant should be run of sufficient capacity to carry the class *A* load for 10 days for the first minute (or less) plus an additional day for each additional minute of duration of interruption; the time of running for each succeeding interruption to be compounded 20 per cent.

That is to say, for the

First	interruption	10	days	plus	1	day	additional	min.
Second	"	12	"	"	1.2	days	"	"
Third	"	14.4	"	"	1.44	"	"	"

et cetera.

And that at the same time sufficient additional capacity of the steam plant should be run to carry the class *B* load for 10 days for the first minute (or less) plus an additional day for each additional minute of duration of interruption; the time of running for each succeeding interruption to be compounded 10 per cent.

That is to say, for the

First	interruption	10	days	plus	1	day	per	additional	min.
Second	"	11	"	"	1.1	days	"	"	"
Third	"	12.1	"	"	1.21	"	"	"	"

et cetera.

In case an interruption should occur before the insurance feature had been entirely worked out on a previous interruption, then the remaining days of operation of the steam plant for the interruption previously experienced should be discarded and a fresh start made for another run of the steam plant, just as though the new interruption had occurred after, instead of during, a running period.

It was further provided that for the first two interruptions experienced in the 12-months period, the steam plant was to be run at the expense of the central-station company, on the assumption that two interruptions might occur even if the supply were from the steam plant alone. The expense of all subsequent operation of the steam plant was to be borne by the hydroelectric company.

Many other methods of penalties and insurance are in vogue, but as this plan is believed to be new it is submitted for discussion and for comparison with other methods already known to the members of the Institute.

4. *Methods of charging.* So many different methods of charging—or, perhaps, modifications of fundamental methods of charging—have been used that it is not surprising that even those skilled in the art are not familiar with all the deviations or the reasons for them.

The individual user cannot afford to pay more than the value of the service to him. The cost to him of supplying his own requirements will depend on (*a*), the maximum capacity he may demand, regardless of when this demand may occur, and (*b*), the total amount of current generated. His investment will be influenced by certain preparatory charges; and, generally speaking, the larger the capacity installed the less the cost on a unit basis of capacity.

While not always recognized, the cost of operation will be influenced, not only by the load-factor, but by the form of the load curve. Similar load-factors do not necessarily mean the same cost for current unless the shape of the load curve is the same.

The value to the user of the service from the hydroelectric company will depend upon what it will cost him to supply his own service; or, what service will cost him from some other source. The cost of service to the supplying company will depend, primarily, on the maximum capacity demanded by each consumer at the time of the maximum simultaneous peak on the station and transmission lines, and, in addition to this, the amount of current generated.

Where the customer supplies himself, he generally does so by the use of steam equipment. The larger items of his expense are those occasioned by the amount of current generated; the lesser items of expense are his fixed charges—which would come under the general term of " investment charges ".

While the value to the user of the service of the hydroelectric company as compared to his own source of supply depends largely upon his absolute peak, the cost to the supplying company depends primarily on the demand of this consumer at the time of the hydroelectric company's simultaneous peak. Non-coincidence of maximum demands is, however, a legitimate source of profit to any supplying company; and this non-coincidence of maximum demands is generally a primary source of profit to the supplying company.

In each case, however, the value of the service to the consumer and the cost of the service to the producer depends primarily on the capacity demanded and the amount of current used. This is assuming that we are dealing with relatively large consumers.

In central-station practice large numbers of consumers are eventually developed having so small a current consumption and maximum demand that what might be termed the " consumer charge "—if it can be designated by this name without further explanation—assumes so much greater importance that it cannot be neglected. In fact, the condition has been reached where a large group of our central-station consumers requires a greater investment and maintenance expenditure for meters alone than is required for the generating equipment necessary to supply them.

It is unfortunate that it is not better understood that there is more than one factor which goes to make up the cost of electric service. Talking of power in terms of charges per unit of demand only, or in terms of kilowatt-hours only, has led to much confusion and many costly blunders. If capacity and current were not jumbled together, and if the value and cost of each were better understood, it would do much to contribute to further development of electric service sales.

The capacity cost to supply many consumers is far greater to the hydroelectric company than would this same cost be if the consumer supplied himself. On the other hand, the cost for current to the hydroelectric company is generally very small compared with the cost to the consumer were he to supply himself.

The capacity the consumer should pay for should generally be based upon his absolute maximum peak experienced at any period throughout the year. Any other method of arriving at the capacity charge is apt to lead to great inequities.

5. *Classes of service which can be advantageously supplied.* In the previous sub-heading attention has been called to the fact that there is more than one factor in the cost or value of electric service supply, and that the factor of capacity is apt to cost the hydroelectric company more than it costs the consumer.

If we were to assume that the maximum demands of all consumers occur simultaneously, then it is apparent that a point is apt to be reached where the total cost of service for any consumer is greater to the hydroelectric company than would be the cost of service to the individual consumer were he to supply himself; because if the capacity cost is greater there may not be enough current sold at the price charged to overcome the higher cost for capacity. Many consumers could therefore supply from their own plants all, or a portion, of their demand, over and above their average demand, at a cost to themselves less than to the hydroelectric company.

To illustrate more specifically, and preferably expressing values in mere arbitrary units instead of in dollars and cents: The cost of service from an individual steam plant might be represented by 100,000 units per kilowatt of capacity plus 100 units for each kilowatt-hour, while the cost of service from a hydroelectric company might be as much as 400,000 units per kilowatt of capacity plus 10 units per kilowatt-hour, being a relation in the first case as 1 is to 1,000 and in the second case as 1 is to 40,000. In spite of this great discrepancy in the relation between the fixed and output factors in the two cases, there is, nevertheless, the same cost of service at approximately 38 per cent load-factor. With a load-factor of less than 38 per cent the cost of service from the steam plant is the lesser, and at more than 38 per cent load-factor the cost of service from the hydroelectric plant is the lesser.

By securing a number of consumers of a diversified character, even though more transmission lines are necessary, a good load-factor can often be secured in spite of the fact that the individual consumers may have poor load-factors. And by getting consumers to adapt their operations to the ability of the hydroelectric company to supply—that is to say, by using some form of what is now called " limited service "—this same end can be realized.

No general and complete rules can be laid down whereby the maximum load-factor can be secured to a hydroelectric company. Rational methods of charging, properly explained so they can be understood both by consumers and by prospective consumers, will do much to contribute to a good load-factor.

The future situation in the hydroelectric supply business will, however, eventually be that of the market greatly exceeding the supply, and the natural remedy will be the installation of steam plants by the hydroelectric companies to enable all possible available water to be used. Central-station steam-power plants have been made a success in competition with individual steam plants, and the success of steam plants in connection with hydroelectric plants should be even more pronounced.

6. *How to develop the market selected.* Many disappointments have been due to failure do develop the available market, or by tardy development of this market.

Few people seem to realize the costliness of tardy operations. A completed plant with an undeveloped load can create a deficit of expected earnings which will require many months of subsequent operation to wipe out.

If the writer were to attempt the development of many of the large prospective water power undertakings, the transmission lines would be completed at the earliest possible moment, regardless of when the hydraulic generating plant could be put in commission; and if steam plants could not be taken over from prospective consumers to give in the aggregate enough capacity to carry on the development of the load, a relatively small steam plant in connection with the initial development of the water power plant would be installed new, and would be added to as rapidly as required to insure a proper load when the hydroelectric generating station was placed in commission.

Delays in securing business are often due to the inability of industrial establishments to change over their equipment until a natural period of shutdown occurs; and failure to take advantage of one of these natural periods may defer the time of getting this business for a matter of many months, or perhaps years.

The financial inability or indisposition of industrial plants to equip themselves with drives often occasions a serious retardation in the development of the expected load, and many power companies would find it greatly to their advantage to have financed the expense for their customers to use electric power even though compelled to take long deferred payments and more or less risk.

7. *How to figure the amount of power it would pay to develop.* It is the writer's belief that eventually hydroelectric companies will develop and sell all of the power that can be generated economically. To do this, in the absence of extensive reservoir capacity, will necessitate a heat engine auxiliary plant to supplement the hydraulic plant during low-water periods. The writer has no suggestion to make for the various purely local conditions which often must be met; but if a complete economic development is ever at all likely, then the design of the plant should be of a character adapted to such ultimate development.

A word on what this maximum development may be will not be out of place. Let us assume a hydroelectric development having simply a dam from which the water immediately enters the turbines and is immediately discharged to the river below the dam without any expensive canals, flumes, etc. In this character of development, hydraulic apparatus can be installed for carrying the peak load at a very much lower cost per kilowatt of capacity than by the use of steam. Not only this, but in this character of development all inequalities of load should be taken care of in the hydraulic plant; and if it is necessary to run steam, the steam load should be run for such time, and at a uniform rate, as will secure the most economic generation of steam power.

Steam plants or steam units can be started up and shut down only at considerable expense, while water units can be started up and shut down at practically no expense.

In the character of development used above as an example, with a market which far exceeds the water supply, and where fuel is relatively high, the hydraulic capacity installed can be equal to the maximum four days' supply of the stream. That is to say, the operation of a water turbine for 100 hours per year will, in some cases, warrant its installation. Under present practice most of us are only developing the so-called secondary power, which can be secured for a period of 10, or at least 8, months.

8. *Calculations on depreciation.* The writer does not wish to appear as viewing the water power problem from a purely financial standpoint, but still it is the financial standpoint which determines whether a water power shall or shall not be developed.

If anybody will agree to furnish the money, there are plenty of men who will agree to furnish all of the other ingredients for developing complete water powers at a rate at least twenty times the present rate of development.

So, after all, it is the financial aspect of the problem which practically controls the entire situation; and matters which unfavorably influence the financial aspect are matters to which we can well afford to direct our attention.

The question of depreciation is one which has an important bearing. Practically all of the present assumptions for depreciation are too high. Figures applied to depreciation are used in a general sense without regard to what the plant consists of.

The character of construction will largely influence the rate of depreciation. It is manifest that a plant having 10 per cent of its investment in wooden poles and 20 per cent of its investment in a masonry dam will have a higher rate of depreciation than the plant which has only 2 per cent of its entire investment in wooden poles and over 50 per cent of its entire investment in a masonry dam. Each individual class of property should be given its own true rate of depreciation, if any depreciation at all is to be figured, or else the different parts of the plant having the same relative rate of depreciation must be grouped together in figuring what the total depreciation will be on the entire property.

9. *Methods to determine the accuracy of engineers' estimates.* The writer has but one point in mind to speak about under this heading, although the importance of this subject would warrant more extended consideration. Without anything new to offer,

the writer desires simply to lay stress upon the point of greatest value.

Omissions and miscalculations are natural things to expect, and are always apt to be present. Checking and rechecking plans by the same, or other, engineers may not disclose the omissions or errors, while complete independent reports by two or more separate engineering corps, and the comparison of these reports, will practically insure against all omission and all miscalculations, making it possible to do the development work for the cost anticipated with a realization of all the power and the expected market at the price predicted.

Conclusions

Now, what has already been said may be considered simply as a preface to that which is primarily in the mind of the writer. Owing to the great breadth of the subject, no effort has been made to go into great detail, or to offer numerous specific suggestions, but only to make such comments as would arouse sufficient interest in the broad subject to produce further specific work.

It is hoped that the discussion which this paper may provoke will bring out much of value to further the development and operation of hydroelectric plants and lead to effective future work along these lines. The problem is worthy of consideration from many different points of view. The whole public has been aroused by, and applauds, the movement to conserve our natural resources. Nothing can contribute more to this desired end than the speedy development of our water powers.

Lack of knowledge (or faith) on the part of engineers, investors, public officials, and power purchasers is the greatest factor of retardation. No other existing body can contribute as much to the betterment of present conditions as can this Institute.

Our individual engineers and our engineering organizations enjoy positions of great influence with the general public, and this influence offers splendid opportunities for shaping the opinions of those elements of the public necessary to the development of these projects.

The Institute can do valuable work:

1. By educating the public to the recognition of the value of hydroelectric securities.
2. By such consideration and discussion as will bring about a

proper attitude on the part of the public officials toward the development of our water powers.

3. By papers and discussion on the methods of planning and developing which will insure that existing streams will be developed so as to realize more nearly their maximum economic possibilities.

4. By papers and discussion on projects collateral to hydroelectric development, calling attention to and enumerating what these opportunities are and indicating how and where necessary additional information can be obtained.

5. By encouraging frank and open discussion of past errors and their cause. The whispered gossip of alleged errors and failures to realize expectations are generally hopelessly inaccurate and prompted more by professional jealousy than by the desire to impart knowledge.

6. By the consideration of methods and equipment to insure continuity of service and of penalties for and insurance against interruptions. Had time permitted, the writer would have compiled a list, as far as possible, of all causes for interruptions which have been experienced.

7. By educational work on methods of charging, rates of charging, and factors which go to make up the cost and value of service, coupled with the endeavor to standardize all terms of expression.

DISCUSSION ON "TELEGRAPH AND TELEPHONE SYSTEMS AS AFFECTED BY ALTERNATING-CURRENT LINES." NEW YORK, OCTOBER 8, 1909

(*Subject to final revision for the Transactions.*)

President Stillwell: From the earliest days men have found themselves discussing and frequently quarreling over property interests. In comparatively modern times the question of right-of-way has been raised frequently in an acute form as between railroads and streets and wagon roads belonging to municipalities or townships; and for a considerable number of years also, more especially in Europe, there have been questions in regard to what I may call aerial rights-of-way, the right to sunlight intercepted by the erection of buildings.

The question of right-of-way in ether is strictly modern. It arose first in the shape of damage caused by electrolysis, due to the utilization of the earth by electric railways, as return conductor for the currents used for motive power; the electrolytic action set up by these currents causing, in some cases, more or less damage to existing sub-surface structures. This interference has raised and is still raising some interesting questions in regard to prior rights. These questions have not been fully adjudicated, but the courts in general have decided substantially that no individual interest can own the earth; that adjustment must be sought along reasonable lines; and that the principle of give and take must be recognized.

It is the business of scientists, particularly of those who have to do with applied science, as have the members of this Institute, first to ascertain the facts in any case of this kind and then to seek by scientific means to eliminate causes of conflict; in brief, to find a cure, or a preventive, rather than to let the conflicting property interests go to the length of opposing each other in the courts. The procedure should be science first, and then, if science cannot find a cure, the principles of justice and fair-play may be relied upon to effect a final adjustment. It is highly important, I believe, that engineers should take the reasonable and just view and not the partisan view on questions of this kind.

The action of a committee of the American Water Works Association some years ago illustrates the opposite policy. The recommendation of that committee was adopted by the association named, and it stands to-day as the pronouncement of that association in regard to what should be done in respect of conditions that cause electrolysis. The position is unsound and could not be maintained for a moment in a court of justice. That an engineering body, or a quasi-engineering body, should take a position unsound and unreasonable is unfortunate. The position taken amounts, in effect, to a declaration that electric railways shall not be permitted to use a grounded return; that they shall keep off the earth and shall double trolley all lines.

We are fortunate in this Institute in having a membership that is interested primarily in scientific facts, and in finding reasonable and effective remedies for difficulties as they arise. I have very great pleasure in introducing Mr. J. B. Taylor, who will read the first paper before the Institute on this interesting apparent interference with the operation of telegraph and telephone systems by parallel alternating-current power circuits.

Charles F. Scott: The interference between electric circuits is of three fundamental kinds. An adjacent circuit may receive from an alternating-current circuit: 1, effects due to leakage; 2, effects due to electrostatic induction; and 3, effects due to electromagnetic induction. These interferences are not separate and independent, but are often intermingled in an intricate and confusing way. A brief reference is made in the paper to a method of neutralizing the effect of a single-phase railway circuit upon an adjacent telegraph circuit, which I have been personally much interested in and will therefore describe in some detail.

Some years ago it was recognized that the inductive effects produced in a circuit adjacent to a single-phase railway in which a large current is carried a long distance would probably cause disturbances in the adjacent circuits, and that these disturbances could not reasonably be avoided by readjustments or modifications of the circuits in any simple way. When, therefore, the inductive action is likely to go beyond moderate limits, some means becomes necessary for counteracting its effects in the telegraph wires. From the information and experience at hand at that time I concluded that the electromagnetic induction would be the most serious element, and I set about to devise some method of counteracting it.

The first and most obvious arrangement that presented itself is one to which Mr. Taylor has referred, in which a transformer has one coil in the trolley circuit and a second coil connected in series with the telegraph wire in such a direction that the electromotive force of the secondary of the transformer opposes the electromotive force induced in the telegraph line. This is in effect a special form of transposition. In ordinary transposition the adjacent sections of the circuit are transposed so that the induction in one section opposes that in the adjacent section. It is impracticable, however, to transpose a telegraph line with earth return, so additional sections in the form of transformer secondary coils are introduced which can be reversed; each section of line in which an electromotive force is induced by the current in the railway circuit is followed by a transformer secondary coil in which an equal and opposite electromotive force is induced by the current in the primary coil.

This plan might serve for a definite fixed condition, but railway operation unfortunately involves many variables. As the load is shifting, induction in the telegraph wire will change continuously as the train moves, while the induction in the transformer changes instantly when the train passes it. Moreover, the induction in the telegraph line is not proportional to the current in the trolley wire, but depends also upon the proportion of the current which flows in the rails and that which flows in the earth. This variable proportion is dependent upon the number of tracks, the distance from the train, and other conditions.

I then proposed to wind the primary of the transformer differentially by including certain turns in series with the trolley and other turns in series with the rail, so as to make the electromotive force induced in the transformer more nearly equal to that induced in the line. While this did not offer a complete remedy, it appeared to be a step in the right direction and worthy of trial. I turned the matter over to Mr. A. J. Sweet, asking that he design a transformer for trial test. In a few days he reported that he had studied out a modification that would overcome the fundamental objections to the transformer with double primary coils. He then described a method, that was adopted on the telegraph circuits paralleling the electrified portion of the New York, New Haven & Hartford Railroad. The method is briefly referred to in Mr. Taylor's paper.

A neutralizing circuit having practically the same exposure as the telegraph wire is employed as the primary circuit for supplying the neutralizing transformer. This in turn gives a secondary electromotive force practically equal to that induced in the telegraph wire. The two are connected in opposition. A careful study of this system brought out its many advantages. Experimental tests were made, both in the laboratory and in connection with a single-phase interurban railway on which, during the tests, very heavy currents were employed in order to induce a considerable electromotive force in the circuit under test.

In order to appreciate more fully the intricate problem which is presented it is interesting to note the principal variables that affect the electromotive force produced in an adjacent wire:

1. The current in the trolley wire, the amount of which varies with the load.

2. The current in the rails. The return current divides between rails and earth in different proportions under different conditions.

3. The current in the earth and the effective position of this current. Suffice it to say that the actual effective current does not flow where the mathematical image directs, but diffuses itself in accordance with unknown physical conditions within the earth and scarcely less mysterious laws of distribution.

4. The phase of the current, which is not the same in the trolley, the track, and the earth.

5. The length of exposure, which depends upon the varying position of moving trains.

6. The distance from the railway or primary circuit to the telegraph wire. In a road with two or more tracks, any one of which may be in service, the effective distance is liable to change without notice.

Now all of these variables have their effect upon a telegraph wire, and there is no other place where a like effect is produced. Therefore, a circuit on the same poles that carry the telegraph wires—and having therefore substantially the same electromotive force in it as is induced in the telegraph wires—should be made to introduce a counter electromotive force in the telegraph wire, so that the counter effect may vary in the same way as the initial effect. When the transformer primary coil is connected in series with the neutralizing circuit, the electromotive force produced upon a secondary coil having the same number of turns as the primary will be slightly less than the induced electromotive force in the primary circuit on account of the drop due to resistance of the neutralizing circuit. In order that the electromotive force on the secondary may be equal to that induced in the telegraph circuit, it is obviously necessary to have a few more turns on the secondary coil than on the primary. By using a suitable number of turns, the electromotive force on the secondary is made practically identical with the electromotive force in the telegraph wires. The tendency for alternating current to flow in the telegraph circuit is therefore eliminated. As a matter of fact, there is a slight difference of phase between the secondary electromotive force of the transformer and that of the telegraph wire. Methods have been proposed, and tested, for reducing or eliminating this difference of phase, but it has not been found necessary in practice to employ them.

As the secondary coil carries no alternating current, the transformer acts as if on open circuit. The transformer may therefore carry a number of secondary coils, each connected to its own telegraph circuit. It is found that the secondary coils introduce but little impedance into the telegraph circuits, and that the increased mutual induction between telegraph circuits is inappreciable.

The arrangement and capacity of the neutralizing transformer are adapted to the particular conditions in which it is to be placed. The neutralizing circuit is grounded just beyond the ends of the exposed section. If this is long, two or more neutralizing transformers may be installed, and the neutralizing circuit may preferably be grounded midway between adjacent transformers.

Some time before the electric service was inaugurated on the New Haven road, the engineers of the telegraph company made inquiry in regard to the conditions which might be anticipated. These conditions were discussed and the above-described system of neutralizing transformers was explained. Tests followed, and a request was made for general specifications for the installation of the system. This was prepared and a transformer was designed for the service. An order was placed for a number of transformers about a year before the electric service was starte The transformers were built and installed and are now operating as originally designed. The transformer is of the simplest type and is adequate for handling a large number of telegraph circuits. The transformers along the New Haven road are arranged for the accommodation of thirty telegraph wires. Preliminary tests were made by A. W. Copley as soon as current was available, in order to determine the best ratio of primary and secondary turns and to observe the operation of the system. It was found that the residual electromotive force is only a few per cent of the induced electromotive force. It was also noted that the neutralization became less effective when a large number of telegraph circuits were connected. It was found that the direct current in the telegraph circuits magnetized and saturated the core of the transformer, which in turn increased the primary magnetizing current and the loss in the primary circuit. This could be obviated by reversing the battery on part of the telegraph circuits or by introducing an auxiliary direct-current coil. These precautions have, however, not been introduced in practice.

It may be noted in connection with this system that it is independent of the railway circuits. There is no introduction of coils into the trolley or the rail circuits. There is no danger of connection between trolley circuits and telegraph wires due to defects in the transformers. There are no moving parts or elements requiring adjustment.

It was found that the electrostatic effect upon the telegraph wires, although paralleling a 10,000-volt trolley at a distance of only a few feet, appears to be nil on the New Haven system. This is presumably due to the considerable number of telegraph wires which probably distributed the charge among themselves, and, as these wires are grounded in regular service, the effects due to electrostatic induction have introduced no serious effects, and, indeed, have failed to be discovered.

Mr. Taylor's paper is, as he states, a general one and introduces a number of suggestions indicating an academic standpoint, as they are suggestions illustrating the principles involved in certain theoretical methods rather than methods to be carried out in practical specifications. Nevertheless, I think it not unlikely that some of his suggestions might be taken by persons not familiar with engineering conditions as rather simple and easy remedies for overcoming all practical difficulties. For example, it is very easy do draw on a diagram a potential neutralizing conductor parallel and close to a trolley wire; but the running of a second conductor having a difference of 20,000 volts in potential from a trolley, and maintaining it in close proximity to the trolley wire, is easier on paper than it is over a railroad. Again, the suggestion is made of running a second wire for carrying the return current. It is not a simple matter to support and maintain a heavy grounded conductor near the trolley wire. With regard to the arrangements that I am just referring to, the middle diagram of Fig. 20, shows a transformer electrically linking the trolley wire and an overhead return conductor, the purpose being to carry the return current by the overhead conductor instead of by the track; and it is stated on the top of the next page that the inductive drop may be considerably less than with the earth as a return, which may be an important factor in some cases. I doubt whether under practical conditions that would be found to be so. True, the two conductors are fairly close together; but when the track and the earth constitute one conductor, it is of such large diameter that the self-induction of the circuit is due principally to the overhead conductor.

If, then, the two wires—one the trolley wire and another wire of the same size—be placed, say, two feet apart, the self-induction of the circuit will be somewhat in excess of the self-induction of a circuit consisting of the trolley wire and the track return. The resistance lost in the track and earth return is usually quite small compared to that in the trolley wire. A second wire overhead for the return of the current will considerably increase the resistance lost in the circuit. If that resistance loss is about the admissible limit, then adding a second wire would tend to double that loss; hence the size of the conductors would have to be doubled, making the total weight of the conductor in the trolley and in the return some four times as great as that required in the trolley alone, when the track and earth return is employed.

I notice at the bottom of Table I, under electromagnetic induction, the statement that a slight shielding action is obtained by placing wires in lead-covered cables, or by placing them underground. That is, I think, correct if it is understood that ordinarily the effect is a very small part. I have found many persons who think that if any overhead wire were buried, all of its troubles would be a thing of the past and that electromagnetic induction would not seek it in the earth. On the other hand, the electromagnetic lines which surround à conductor are not affected by the earth, so that whether a wire is placed a little above or a little below the surface of the earth does not make much difference. Thus if a cable is 20 ft. from the trolley, and is midway in height between track and trolley, it does not matter whether the ground is low and the cable is supported on poles, or whether there is a high bank at the side of the track and the cable lies in the earth. It is the position of the cable and not the position of the earth which is of consequence. There may be a little flow of current in the lead shield which will tend to neutralize the field, but that is of minor effect. So that speaking generally, the burying of a wire in a lead-covered shield or cable has, I think, very little effect in reducing the electromagnetic induction.

A. W. Copley: I have had an opportunity to make extensive experimental investigations on the New York, New Haven & Hartford Railroad to determine the nature of disturbances in neighboring telegraph lines caused by current in the railroad power circuit, the causes of such disturbances, and to suggest remedies therefor. In the light of the results of these experiments, there are several points in the paper to which I wish to call attention. Mr. Taylor has given some data for the amount of alternating current that caused chattering in one particular telegraph relay with one particular adjustment. He has said that it is impossible to make a general statement covering all the various conditions of instruments and circuits.

I wish to give similar data obtained by me on artificial lines that were made to approximate closely several conditions obtaining on actual lines. Bad weather conditions were approximated by placing leakages between lines and ground. Several different adjustments were made on the telegraph instruments by a telegraph expert when there was no alternating current in the line, these adjustments being made to correspond with what might be met with in practice. After each adjustment, alternating current was introduced into the circuit in increasing volume, until it began to affect the working of the instruments. The ratio of the alternating voltage to the working direct voltage was then taken. This was tried for alternating currents of both 25 and 15 cycles, and on simplex, duplex, and quadruplex circuits.

The first tests, on simplex circuits were made with box relays in the circuit. These are relays which act as sounders, and with them no local circuit is necessary. These relays showed the effects of the alternating voltage at very low values, the signals becoming uneven and "mushy." This is because the relay gives a sound proportional to the strength of the blow of the armature, and the alternating current varied this strength so as to make some signals strong and some weak. The box relays are seldom used in actual circuits, and therefore no data were recorded under this condition.

The usual simplex circuit uses neutral relays that close local sounder circuits. With these the intensity of the armature stroke has little to do with the distinctness of the signal. Tests made with these relays gave the ratio of allowable alternating voltage to direct working voltage as about 0.5 for 25 cycles, and 0.4 for 15 cycles. The ratio was found not to vary greatly from these values with considerable variations in the circuit conditions, and adjustments of the instruments. Duplex circuits were less sensitive: the ratio in this case averaged 0.9 for 25 cycles, and 0.7 for 15 cycles.

Quadruplex circuits were by far the most sensitive, and showed a great deal of variation; but average values of 0.2 and 0.15 were obtained for the ratios at 25 and 15 cycles respectively.

Results on actual lines confirm closely the above results. Thorough tests in actual lines were made with simplex circuits, but only limited tests were made with either the duplex or quadruplex on actual lines—the ratios given are, of course, only approximations, but they may be taken as practical working limits. I would add, further, that although the allowable 15-cycle voltage is only about 75 per cent of the allowable 25-cycle voltage, the voltage induced by a given amount of current at 15 cycles is only 0.6 of that induced at 25 cycles. Therefore the telegraph lines are slightly better off under the influence of the lower frequency.

It is seen, then, that the disturbance can be overcome if only the working direct voltage is made high enough; this is quite an effective method as long as the direct current is not increased above allowable limits. The method is substantially the same as the second remedy given by Mr. Taylor; that is, increasing the working current. If it is undesirable to increase the current, but increase of voltage is allowable, a combination of his first and second methods may be used—increasing the impedance or resistance of the lines, and at the same time the direct voltage, holding the current constant.

The last remedy, the bug-trap arrangement, might be emphasized. Tests made with this device showed that it was possible to work a simplex line in which the alternating induced voltage had several times the value of the direct voltage; but it was found to be inapplicable to cases where the alternating voltage varied. If the induced voltage is steady the arrangement is quite efficient; if not, the relays must be constantly adjusted.

The reason for the good performance obtained is that as the contact in the local circuit is made on the back contact of the relay, the local circuit is always definitely closed when the sender's key is opened, at which time no current, either alternating or direct, is flowing through the relay. With the sender's key closed, the armature of the relay chatters against the front contact, which is dead, but does not rebound far enough to touch the live back contact. Therefore the local circuit is definitely opened.

The other remedies suggested have been tried, but with little success.

Mr. Taylor has devoted several pages to the calculation of inductive disturbances. He has indicated the importance of knowing the positions and the volumes of the currents in the various parts of the circuit. In particular, it is necessary to know the volume and effective position of the earth current. By effective position I mean the position at which, if all the earth current were concentrated, the same inductive effects would take place as do actually occur. This will be different for wires at different distances from the road, because of the wide distribution of current in the earth. Tests have shown, however, that it can be assumed for practical calculations at one position for wires within a considerable distance.

From theoretical statements in Mr. Taylor's paper, it appears that part of the return current would be found in the rails and part at the image of the trolley wire. But tests made on the New Haven road and at other places indicate that the effective position of the earth current is far below this image; in fact its depth is in the order of ten times the depth of the image.

The amounts of the rail and earth currents were investigated, and the results have been published as part of my discussion of a paper by J. B. Whitehead at the Atlantic City Convention, in 1908.* The figures were also published in the November, 1908, *Electric Journal*. When it was found by test on single-track roads that the earth current was as high as 60 per cent of the trolley current, calculations were made which closely verified this result. Charles F. Scott at that time made calculations for two- and four-track roads, in which the effective diameter of the overhead conductors and the track are much greater than in a single-track road. This condition naturally produced a different magnetic field in the earth below the track, and a different distribution of the earth current, as well as a different ratio between rail and earth currents. The result of the approximate calculation led us to expect about 75 per cent rail current. Subsequent tests showed 80 per cent.

Mr. Scott stated in an editorial in the *Electric Journal*, in November, 1908, that the earth current is largely due to inductive rather than to resistance effects. Supposing the track to be insulated from the earth, and an insulated wire to be buried at a depth of several yards under the track, one end of the wire being connected directly to the rails—then a voltmeter connected between the other end of the wire and the rails will measure a considerable induced secondary voltage. This is in addition to the resistance drop in the rails, the primary circuit being the trolley wire and rails, and the secondary circuit the rails and the buried wire. If the voltmeter be short-circuited, a current will flow in the underground wire. Similarly the earth acts as a connection between the ends of the track, and if the latter be not insulated, current will flow from the rails into the earth.

In Fig. 22 Mr. Taylor gives curves, showing the induced electromotive force in neighboring circuits for the two conditions of all current returning by rail, and all returning at the image of the trolley wire. As the effective position of the earth current has proved to be so much lower than the image, and the amount of this current is fairly large, the curves are of little value practically. It is not, however, impossible to fortell approximately the induced electromotive force in a telegraph line. From the tests made on single-track roads we were able to calculate an effective position of the earth current, and from this, together with the calculated proportion of earth current, it was possible to calculate the voltage which might be expected on the New Haven railroad. The actual induced voltage checked to within 10 per cent of the values calculated a year before current was put on the line.

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*PROCEEDINGS, A. I. E. E., December, 1908, p. 1733.

W. S. Murray: I think the best way to discuss this subject, at least from the railroad point of view, is to confine my remarks as closely as possible to the actual facts of the situation. The New York, New Haven & Hartford Railroad Company in their electrification zone has certainly greatly abused the adjacent telegraph and telephone lines by inflicting them with inductive troubles. Without diminishing one iota the meritorious achievements incident to the invention and use of the telegraph and telephone, yet I believe that public opinion, in estimating the usefulness of these three great agents of convenience, would grant, and not unselfishly, in the sense of " the survival of the fittest ", both written and unwritten rights to the railroad. I do not mean to intimate that, by virtue of its predominance over the other two conveniences the railroads should be permitted to abuse their rights and privileges; but if real progress is to be considered, the value of things must be regulated by their importance, and while apparent injustice sometimes may be rendered in the working out of this law of order, in reality public rights of convenience have been conserved.

Mr. Taylor's paper interests me in three different ways: first, because the information presented is concisely stated, and shows the hard work of the author in his effort to offer something useful; secondly, it gives me a clear picture of the troubles that the telegraph and telephone companies have had with a commodity we give them, that in the giving does not cause us any trouble at all; and, thirdly, because I am interested in a single-phase, alternating-current railway that, on account of the arrangement of its circuits, gives to the telegraph and telephone wires in its vicinity the maximum amount of inductive troubles.

Ever since alternating current was transmitted over wires it has been a nuisance to nearly every other electric circuit in the immediate neighborhood. Its only saving grace has been its association with things of maximum importance. The mitigating excuse for its existence is it accomplishments.

Familiar ground is covered in that part of the paper which is confined to the several schemes of arranging wires to neutralize both electrostatic and electromagnetic induction. All of these arrangements were considered during the preparation of our electrification plans. Distribution by polyphase circuits and reversals of direction of current flow by the transformer method were both considered; but all economic features were met, as far as the transmission system was considered *per se*, by the distribution of a single voltage in a single-phase throughout the complete system. Though conscious of the fact that this decision prescribed severe inductive troubles upon the lines of the adjacent telegraph and telephone companies, yet in the same moment of this decision we united with them in a search to find the remedy for their difficulties. The cost to the railroad company partly to eliminate the inductive effect of its power circuits would be many times that to the telegraph and tele phone company to guard against this effect. Mr. Taylor's paper intimates this conclusion; our actual calculations justify it.

In regard to the summary given at the end of Mr. Taylor's paper, I am in agreement with the statements made in the first paragraph, except the last sentence. It seems to me that the ideal metallic circuit, if subjected to a magnetic field, would be disturbed to the extent of having its potential raised above the earth; for example, one standing on the ground and touching the circuit would receive a voltage in proportion to the frequency, length of circuit, and number of lines of force cut.

I agree with the second paragraph.

I agree with the third paragraph, assuming that no auxiliary apparatus is used to meet the disturbing condition.

I agree with the first sentence of the fourth paragraph, but ask if the compensating transformer that derives its primary voltage from both earth and wire potential does not virtually provide a secondary voltage in complete compensation for voltage in the telegraph wire and its ground return?

I agree with the fifth and sixth paragraphs.

In order to ascertain the actual conditions that exist to-day, and give some line on the results obtained in an effort to compensate for the induction suffered by lines adjacent to our electrification, on Tuesday, October 5—a few days ago—a conference was arranged, at which were present Messrs. N. E. Smith superintendent of telegraph, B. D. Hubbard, chief operator in the general offices of the New Haven road, and Michael Kelly, district repairman, stationed at Stamford, Conn., in charge of all repairs in the electric zone for the Western Union Telegraph Company. Mr. Hubbard being constantly stationed at the end of the telegraph lines that pass through the electric zone, Mr. Kelly being in charge of such repairs as were required to these lines, and Mr. Smith being in general charge of telegraph operation, it occurred to me that a general conference would develop the difficulties experienced and the methods pursued to rectify the troubles—all of which would throw light on the actual results obtained since the electrification zone between Stamford and Woodlawn has been considered as completed.

The memorandum of categorical questions I asked at this conference is as follows:

Question. How many telegraph lines are you operating in the electric zone?

Answer. Ten railroad lines, seven Western Union, and three spares.

Q. Would these lines be operative without the use of compensating transformers?

A. No.

Q. By reason of the induction present have you ever had any burnouts on these lines?

A. Not since full commercial railway service has been in operation. (Mr. Kelly, however, offered an interesting commentary at this junction. He explained that upon one occasion during the early part of preliminary operation the continuity of the track was broken as a return circuit to the power house by inserting insulating joints at three places. This break caused a rise of voltage and consequent increase of current in one of the compensating transformers, and resulted in the burning out of the transformers. Upon another occasion the telegraph line was crossed with the high-tension railroad circuit, with the attendant result of burning out another compensating transformer. Except for these two cases in the preliminary stage of operation, it seems that no compensating transformers have been lost.)

Q. Are there ever times when by reason of induction any of the lines became inoperative?

(In answer to this question Mr. Hubbard explained that at times, principally during the morning and afternoon—the periods of heavy traction load—the buzzing on one of the through lines between New York and Boston was so severe as to be just outside the limit of adjustment of the instrument, and for a minute or two it would be necessary for the operators to cease communicating. This particular line is known as 72. It developed, however, that this wire from Bridgeport to Boston has an iron circuit, while the other lines from New York to Boston are of copper throughout. I have suggested the use of a copper wire from Bridgeport to Boston, thus increasing the conductivity of 72, which will cut down the ratio of induction to working current. In the event of this rectifying the trouble, it may then be said that at no time will any of the twenty wires in the electric zone be inoperative, due to induction. It is fair also to add that Mr. Hubbard explained the excessive buzzing described on 72, as quite exceptional.)

Q. Has the Western Union Company made any complaints concerning the ten wires which lead from our electric zone to their New York office?

A. No complaints in the last year, beyond ordinary telegraphic troubles.

Q. Are there any complaints made about the wires by the operators in the general offices of the New Haven road?

A. None.

Q. What is the extra maintenance required by reason of the addition of the compensating transformers on your telegraph lines in the electric zone?

A. There are more fuse blow-outs, escapes, and grounds.

Q. Are these troubles so numerous as to affect the efficiency of telegraphic transmission?

A. There have been no complaints in regard to the availability of the lines for service. These new occurrences simply require an extra inspection, which was not required under the old conditions.

Q. Under what conditions do you experience these troubles?

A. The failure of an insulator on the catenary system is generally the cause of a telegraph fuse blow-out, the starting of an escape, or a ground. (This effect is pointed out on the first page of Mr. Taylor's paper.)

Q. How often do you inspect the compensating transformers?

A. Each transformer is inspected about twice a month.

Q. Do fuse blow-outs, escapes, and grounds occur in any one particular point on the electric zone?

A. Yes, at Portchester, for example, where telegraph lines run more closely to the high-tension wires than at any other part of the zone.

It is fair to say that the index of efficiency in telegraphic service is the number and reliability of messages per unit of time. Likewise in railroading its index is the number of locomotive-miles per engine failure. Our records for the month of July 1909, show that the electric locomotive mileage was 14,000 miles per engine failure, while for steam the figure was 6238 miles per engine failure. Thus the steam record was less than 45 per cent as good as the electric.

In conclusion the writer cannot refrain from pointing to the two kinds of trouble—surmountable and insurmountable. The New Haven electrification, in turning out trouble to its friends, the telegraph and telephone, was not selfish and did not forget to lay a few eggs in its own nest. Some of these were hatched, but I am glad to be able to add that this class of offspring lived only long enough to make a record of its birth. While the first installation of the single-phase system as arranged on the New Haven road produces maximum induction, it is not uninteresting to note that as extensions of this system take place, by reason of power stations delivering current that virtually divides itself in equal amounts and in opposite directions along the righ-of-way, the inductive effects will tend to eliminate themselves, and the future will be more free from them than the present.

Charles P. Steinmetz. I consider Mr. Taylor's paper as particularly inportant because it is a complete and explicit exposition of the relations between the two classes of electrical transmission – the transmission of power and the transmission of intelligence.

We know that electric power circuits may, and occasionally do interfere with their weaker brothers, the telegraph and the telephone systems. The problem before us now—which is not a problem of interest only to the power engineer or the railway man or the telegraph engineer, but one of great importance to the electrical engineering industry at large—cannot be solved by saying that we are power engineers and expect the telegraph and telephone systems to take care of themselves. This would be as unfair and as untenable as it would be for the telegraph or telephone engineers to say: we were the first ones in the field and must not be interfered with, and we insist that the electric power systems shall be installed in such a manner as not to interfere with us. As stated by President Stillwell, the latter short-sighted policy has been manifested by the American Water Works Association.

Mr. Taylor's paper shows us that from the engineering point of view neither of these policies is tenable, and that the question can only be solved by coöperation between these two classes of engineers. The power engineer must make some concessions in the arrangement of his system to reduce interference, and the telegraph and telephone engineer must be willing to go to some inconvenience to protect his system against interference which cannot be avoided by the power engineer. It behooves us power engineers to give consideration to our weaker brothers, the telegraph and telephone systems, who are being interfered with by our circuits and who cannot interfere with us; for while we are to-day the stronger, sometime we may be the weaker, and then ready to cry out for protection when powerful ether waves from nearby wireless telegraph stations cause trouble in our low-voltage lighting circuits.

While with the advance of the electrical industry we are obliged to specialize more and more, at the same time this advance brings us closer together and makes us more and more dependent upon each other, obliges us more to consider the interests of others and not simply our own particular field. Mr. Taylor's paper is, therefore, of extreme interest not only to the telephone and telegraph engineer, but also to the power engineer, by drawing attention to these interferences and showing how they originate, or what character they are, and indicating in general the arrangements which may be used to mitigate or obviate them. Obviously, the paper can be only a broad outline, since it is the first paper on the mutual relation between the telegraph and the telephone on one side and electric power on the other side. It is therefore regrettable that the telegraph and telephone engineers could not be induced to discuss the subject here and to give us the benefit of their ideas.

Coming to a more specific discussion of the paper, Fig. 14 shows a diagram of an arc circuit which goes out on one street and comes back on another street in another part of town, looping a city block or an entire city district. Such loops of overhead alternating arc wires are extremely bad for the telephone and telegraph circuits, but fortunately they are going more and more out of use.

I cannot agree with Mr. Taylor's explanation of the greater frequency of grounds on arc circuits as being due to the higher voltage. It appears to me that the fact that arc circuits are more liable to faults and grounds than primary distribution circuits is due to the nature of their load. The arc circuit feeds directly into the consuming devices—arc lamps. The primary distribution circuit feeds only into transforming devices—transformers which are relatively small in number and can be very well insulated—while the arc lamp cannot be insulated to stand the voltage between the arc circuit and the ground and therefore must remain a part of the arc circuit, is to be considered as alive, and leads to a greater liability of trouble from grounds and faults by contact with trees, etc. This condition is aggravated by the limitations in the location of arc circuits, which cannot choose their path, but must run wherever arc lamps are desired, even if they have to go through trees, etc. The primary distribution circuit has a greater choice of its path in choosing the location of the transformer so as to give the least chance to interference. The result is that the arc circuit is always much more liable to grounds. Incidentally, a ground in an arc circuit is very much less troublesome, because current and power are limited. For this very reason it has become almost the general custom where arcs are operated from alternating-current systems to separate the arc circuit by a transformer from the primary distribution system; that is, to use constant-current transformers instead of the cheaper constant-current reactances.

I do not quite agree with Mr. Taylor on the improbability of trouble from the third harmonic of the generator wave, for the reason that my first introduction to the third harmonic took place ten or twelve years ago when we grounded the generator neutral in the Mechanicsville–Schenectady transmission. The telephone line on the same poles was put out of service entirely, and we were obliged to take off the ground—and then the telephone line operated again. Undoubtedly by a proper arrangement of telephone wires and power wires, as described in Mr. Taylor's paper, operation could have been made satisfactory; nevertheless, as it was installed, the telephone circuit was satisfactory with an ungrounded neutral and was not satisfactory with a grounded neutral. At that time we took an oscillogram of the neutral current and found the third harmonic very greatly distorted by the ninth harmonic. Since the frequency was 40 cycles, the ninth harmonic, of 540 cycles, was fairly close to the maximum sensitivity of the ear. This illustrates what Mr. Taylor has said, that one may expect more trouble from the higher harmonics of the generator, since these higher harmonics have a greater physiological equivalent in the ear than has the fundamental.

Regarding the image conductor, its meaning is frequently misunderstood. The image conductor; that is, the image below the ground, of the trolley wire, does not mean that the center of the return current is in it. It means: if we assume that the ground is a perfect conductor and that the return current therefore does not penetrate at all below the ground, but flows entirely at the surface of the ground, as a current sheet, then the inductance of the trolley wire against this current sheet at the surface of the ground would be the same as the inductance of the trolley wire against the image conductor. As the ground is not a perfect conductor, the current does not flow at the surface but flows at least partly some distance below the surface; as a result thereof the inductance of the trolley is not that of the trolley wire against the image conductor but is greater, corresponding to an image conductor deeper below the ground, as was mentioned by Mr. Copley as a result of the tests on the New Haven system. Especially in a steam railroad system, where the road-bed and the soil near the surface are probably of relatively high resistance, the current returns, not at the very surface but at a considerable distance below it. This means that the equivalent return conductor, that conductor below the ground which would give the same self-inductance to the trolley wire, would be very much deeper than the image conductor. The image conductor must not be mistaken for the center of the return current; it is a representation of the current sheet at the surface.

The great difficulty with the theoretical investigation of these disturbances is the complexity of the circuits for which we have to calculate the mutual inductance and the mutual capacity, and here we find that the greatest trouble is in the calculation of the mutual capacity. Regarding the mutual inductance, some uncertainty may exist in the location of the return circuit as to whether it is close to the surface or deeper in the ground, but the difference in the numerical value produced thereby is not very great. In his conception of the lines of magnetic force, Farady has given us such a beautiful illustration of the magnetic field that we can see it and calculate the magnetic inductance mathematically while knowing exactly what we are doing. This induces confidence in our results. Unfortunately, in the field of electrostatics our mathematical theories are still those of the early dawn of electrical science; we are still dealing with conceptions as they were developed in those days, before the law of conservation of energy, when heat, electricity and magnetism were "imponderables", forms of matter without weight. We speak of such non-existing things as the electrostatic charge of a conductor, the surface density of the electrostatic charge, and discuss the static self-potential of the conductor There is no such thing as an electrostatic charge of a conductor. Since Faraday's time, in the field of magnetism we do not speak of the magnetic charge of a magnet, but in electrostatics we still have the antiquated conception of an electric charge, instead of considering the effect as an electrostatic field in space. What is necessary now is that some Faraday give us as clear a conception of the electrostatic field as we have of the electromagnetic field, so that we can deal with the lines of electrostatic force, not with the antiquated conception of electrostatic charges which are suitable for mathematical formulas, but in which we cannot see physically the meaning of the mathematical representation; for, so long as we cannot see the physical meaning, we can have no confidence in the correctness of the methods we are using.

Unfortunately at present the probability of the reduction of the conceptions of electrostatic phenomena to the same simplicity and obviousness, if I may so term it, as that of electromagnetic phenomena is unlikely, since most of the investigators have been carried away by the prevailing fad of representing the phenomena of electric power flow, not as Faraday and Maxwell did, as conditions of stress in the space—as an electric field—but as due to the migration of some form of dematerialized matter, the electrons, between the molecules of matter. Before we can get a clearer conception it will be necessary for some genius to take up this electronic theory and separate the mass of chaff from the few grains of truth, and so make the ionic theory a useful instrument of research instead of a stumbling block to the advance of exact science, as it is beginning to be at present. Then we will have the electrostatic field as tangible as the electromagnetic field is now.

At present, when dealing with electrostatic phenomena, such as the mutual capacity of circuits, the only way I can find that is at all satisfactory and not liable to confuse one, is not to calculate the electrostatic capacities at all, but to calculate the electromagnetic inductance and get the capacity from the inductance by the relation existing between the two by means of the velocity of light. The product of capacity and inductance equals the square of the length divided by the square of the velocity of light. Thus we get the capacity, mutual as well as self-capacity, from the inductance of the circuits, and do not need to consider particular methods of calculating capacities. In calculating capacities from inductance by the velocity of light, the error is that the actual electric velocity is slower than that of light, due to the energy loss in the electric circuit, which retards the velocity. If, however, as inductance we do not use the total inductance of the conductor, but only the external inductance—the logarithmic part—then we eliminate the effect due to the energy loss and get the exact value of the capacity.

L. C. Nicholson (by letter): The author points out the slight cause for transposing a three-phase power line, unless telephone or telegraph lines are near enough to be affected, and in general advises against transpositions for the average case. He does not advise us how near is "near enough", however, and the general conception is that the farther away a telephone line is from a high-tension transmission line the better. To a certain extent this is true, but the limiting distance is not necessarily that determined by inductive effects which could be offset by transpositions, but rather it is that distance which we may call "respectful", which is determined by mechanical considerations, such as liability to accidental contact due to breakage of wires or other similar causes. We wish to cite a concrete case resulting from several years' operation of high-tension, high-power lines in close proximity to parallel telegraph and telephone lines, and to note the negligible inductive and static effects with and without transpositions in the power circuits.

The three-phase, 60,000-volt, 25-cycle transmission lines of the Niagara, Lockport & Ontario Power Company from Niagara Falls to Syracuse run parallel and closely adjacent to the same company's private telephone lines for a distance of 200 miles, and to Western Union telegraph and telephone circuits for 125 miles. The separation between the power lines and the private telephone line varies from 150 ft. to 10 ft., the average distance being about 50 ft., and between the power lines and Western Union lines the average distance is about 70 ft., though frequently not more than 30 ft.

The power lines are transposed only where they are parallel to the Western Union circuits in a manner mentioned below. The private telephone line is a copper circuit on separate poles on the power line right-of-way. The wires are transposed ten times per mile. The Western Union circuits consist of one continuous two-wire telephone circuit transposed twice per mile, and eighteen telegraph ground-return circuits using from 70 to 250 volts storage-battery current.

Originally, and before voltage was put on the power line paralleling the Western Union circuits, transpositions were carefully put in to prevent inductive effects. In a distance of 105 miles, thirty 120-degree transpositions, or ten total transpositions were placed at intervals varying from 3 to 5 miles. The distance between consecutive transposition points was calculated separately for each case from the average separation between the power and telegraph lines, using as a basis one 120-degree transposition every 4 miles for 80 ft. separation between circuits.

After more than a year's operation of this line transmitting some 6000 h.p., during which time no disturbance of any kind arising from normal operation was felt on the adjacent telephone or telegraph lines, eighteen of the thirty transpositions were changed so that the upper conductor was no longer transposed, but remained the upper conductor for a distance of 57 miles. The two lower conductors were transposed 180 degrees at the original transposition points. The remaining twelve 120-degree transpositions covering 48 miles were unchanged. Evidently the 180-degree transposition scheme gives a circuit equivalent to a non-transposed single-phase circuit, the two conductors of which are in a vertical plane with, in this case, 6 ft. separation. During two years' operation of this line with loads as high as 15,000 h.p. no disturbance has been felt on adjacent parallel telephone and telegraph circuits during normal operation. In view of this experience, transpositions of the power wires is considered entirely unnecessary, and in subsequent lines which have been built contiguous to foreign circuits no transpositions have been made.

As stated above, neither the private telephone system nor the Western Union telephone or telegraph circuits can detect the presence of the power circuits when operating normally. However, when a ground occurs on one phase of the power line the electrostatic unbalancing causes chattering of telegraph instruments and sometimes blows fuses in the telegraph or telephone circuits. These disturbances are always of short duration, being usually less than 20 sec., which is the maximum time a ground can remain on any part of the system before being automatically cut off. Electromagnetic effects of a ground are felt only slightly on account of a high resistance placed in the neutral connection to earth of the sending transformers, which allows the passage of approximately 30 amperes earth current. Formerly when the system was operated with a thoroughly grounded neutral, the electromagnetic effects were considerable on account of short-circuit currents to earth, sometimes burning out fuses, relays, and lightning arresters.

Short-circuits between wires do not ordinarily cause inductive disturbances, since when they occur they are nearly always confined to a single location and do not involve the earth as a conductor.

Other forms of abnormal operations have been experienced and their effects upon parallel circuits noted. Single-phase power transmitted over two wires of a three-phase line causes no disturbance.

The combination of transmitting three-phase power approximately one-half the total distance and single-phase power the remaining distance, after the manner shown in *B*, Fig. 15, has never caused any inductive disturbance of any kind.

Transmitting power three-phase over duplicate lines separated from each other several miles, using two conductors of one line and one conductor of the other line to make up a single three-phase circuit, causes disturbances which appear to be due entirely to electromagnetic induction. Thus, normal voltage on only one wire of either line causes no trouble unless considerable three-phase load is delivered—using two wires of the other line—showing that the purely electrostatic effect is negligible under conditions of normal voltage. When, however, a ground occurs on one phase, causing full line-potential to exist between the other two phases to ground, the electrostatic effect shows up in a mild form, as mentioned above.

In general, experience shows that with separation between power and telephone lines as mentioned above, transposition of power wires is unnecessary; that transient electrostatic and electromagnetic effects accompanying grounds on the power line are mild and of slight consequence; that the only class of disturbances that will cause trouble to telephone or telegraph instruments is caused by heavy electromagnetic effects induced by short-circuit currents passing through the earth for considerable distances, as may occur in star-connected, high-power, high-voltage systems which operate with a grounded neutral.

J. C. Barclay (by letter): Mr. Murray has made an assertion to the effect that there is no interference with the telegraph service due to the operation of the single-phase system on the New York, New Haven & Hartford Railroad. This is far from being correct. It is true that by means of the neutralizing transformers interposed in the telegraph circuits at two-mile intervals along the electrified zone, the working of the wires has been rendered more or less feasible, where otherwise complete demoralization of the service would have undoubtedly resulted from the disturbances induced therein; but the impression sought to be conveyed that these transformers have proved a panacea for all the inductive ills to which the wires are subjected, is not at all justified by the facts in the case.

There are various reasons why the neutralizing apparatus is not entirely effective under the present conditions of installation. In the first place, escaping currents from direct-current trolley systems find access to the primary windings of the transformers, the cores of which become magnetized, and diminish the degree of neutralization that might otherwise be secured. The working currents of the telegraph circuits in passing through the secondary windings also excite in the transformer cores an amount of magnetism that varies in proportion to the number of telegraph keys that happen to be open or closed, with corresponding variations in the neutralizing values. And, on account of phase-distortion, the counteracting electromotive forces developed by the action of the transformers are not directed in a manner to bring about complete nullification, even though the magnitude of the nullifying forces could be made equal to that of the disturbing forces.

As a result of such conditions, residual voltages and currents of varying intensity are ever present in the telegraph wires, the detrimental effects of which depend, more or less, upon the length and character of the circuit, and the strength of the working current; but are mostly manifest under unfavorable climatic conditions when the sensibility of the receiving apparatus to such currents is at a maximum.

Tests have shown that these residual or superposed electromotive forces in the wires possess an average pressure of about 15 volts even under normal operating conditions, and although the legibility of the received signals on the regular Morse apparatus may not, as a rule, be perceptibly impaired thereby, there is, nevertheless, a marked depreciation in their character or quality that tends materially to affect the efficiency of the service; for, to quote Mr. Taylor in the paper above alluded to:

> Disturbances on the line which do not actually upset the working, may make considerable difference in the comfort or state of mind in which the operator does his work.

From what has been said with regard to the effects observed on the comparatively insensible Morse apparatus, it naturally follows that the more delicate instruments employed in high-speed and multiplex systems feel more acutely the influence of the disquieting currents; and it may be stated as a matter of fact that such systems can only be operated over wires extending through the electrified zone at a considerable sacrifice of speed and efficiency under the most favorable conditions, and not at all under abnormal conditions of working.

There is no disposition on the part of the writer to be hypercritical in regard to this matter, but as the result of practical experience the fact cannot be too strongly stated and emphasized—that the costly and cumbersome transforming devices, which, in addition to other disadvantages, necessitated the sacrifice of three copper wires to provide a neutralizing circuit, as well as the complete transposition of all the telegraph wires at each of the ten transforming stations along the affected zone.

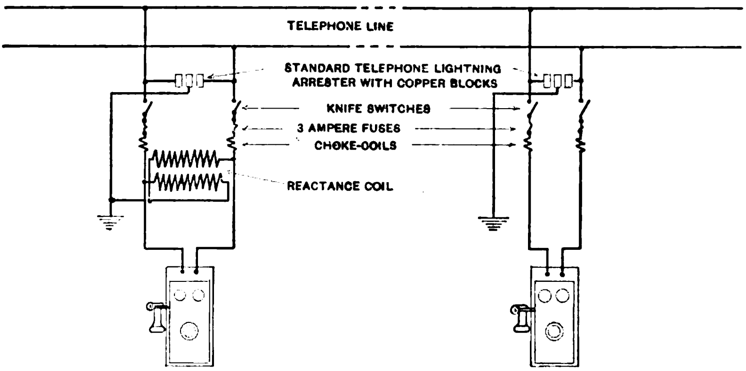
have not brought about a condition in the working of the wires that can in any way be regarded as satisfactory from a telegraph point of view.

A. L. Cook (by letter): In considering the protection of telephone lines for high-tension transmission line service, Mr. Taylor describes an insulating transformer that has been developed to enable a telephone system to be safely used even when a considerable difference of potential exists between the telephone line and ground. The apparatus he describes would undoubtedly protect the user of the telephone, but there are a number of objections to its use. Where there are a large number of telephone stations installed on a long line, it is generally necessary to ring all of the bells simultaneously when calling one of the stations. In this case a considerable amount of current must be transmitted through the transformer at the ringing station and supplied to the transformer at the other stations. In addition to the current actually required for ringing the bells, the magneto-generator must supply the magnetizing current for all the transformers on the line; and while this may be small for a single transformer, with a large number of stations the current required for this purpose would certainly impair the ringing qualities of the line. When talking over the line the voice currents also suffer this same double transformation, and even with the best design possible there is sure to be a noticeable effect on the talking qualities. Unfortunately, the best design of a transformer for ringing service is not the best for talking, consequently any commercial design must be a compromise between these two conflicting requirements. Tests of the particular type of transformer illustrated by Mr. Taylor indicate that the use of one of these transformers affects the talking qualities of a line to about the same extent as would the introduction of five miles of ordinary No. 19 dry paper-insulated telephone cable.

The equipment described is also relatively expensive in first cost, since the cost of the protective apparatus illustrated is more than double that of a good magneto telephone instrument of the type commonly used in this class of work. The principal objection to Mr. Taylor's arrangement is, however, that it does not eliminate the dangerous potential from the telephone system, and for this reason it is only safe to use the line at points where the protective apparatus is installed. It would, therefore, be dangerous for a patrolman to attach a portable telephone set at any point on the line unless he carried around with him the full protective equipment illustrated, which is out of the question because of its size and weight. If patrol stations are located along the line with this protective apparatus installed therein, the telephone system would be very expensive. There is also the objection that with the existence of a high voltage on the telephone line, it becomes more difficult to maintain the system in a satisfactory working condition. If the power wires are not transposed, a high voltage will exist on the telephone line even under normal conditions, and there would be more trouble from leaks on the line, causing a noisy circuit. Even the use of better insulation is only a partial remedy, as the existence of the high voltage would tend to increase the chance of leaks developing. If the power wires are transposed there would normally be no appreciable voltage on the telephone line; but in the event of a ground on a power wire there would be a a very high potential induced, and the insulation of the telephone system might break down at just the time when such a failure would be most serious in its consequences.

The writer believes it is generally better to prevent any possibility of there being a high potential between the telephone line and ground, rather than to attempt to use for purposes of communication what is virtually a high-tension line, so far as danger to life is concerned. The voltage induced on the telephone line may be eliminated by grounding the two wires through reactances or resistances. This method has been used by a number of engineers under widely different conditions, and as far as the writer knows has proved entirely satisfactory. A reactance is more suitable than a resistance for this purpose, as it can be designed to give a very low-resistance path to ground while at the same time the path between the two telephone wires may have a very high impedance to both the ringing and talking voltages. This is accomplished by winding the two circuits on the same iron core, in such a way that the currents flowing to earth through the windings of the reactance neutralize each other as far as any magnetizing effect on the iron core is concerned, and consequently the impedance to ground is only that due to the ohmic resistance of the windings. For the ringing and talking voltages, however, the two windings are in series, so that they offer a high impedance to the working currents; and since these are not subjected to any transformations by the protective apparatus, the maximum efficiency of the line is obtained. In addition to the reactance coils, it is, of course, necessary to provide discharge gaps, set to break down at a low voltage, so that in the event of an accident to the protective coils the telephone line will be grounded and thus rendered safe. With a proper equipment of this character, a patrolman can safely tap the telephone line at any point and communicate with the station, using an ordinary portable set for the purpose. The cost of this type of protection is also considerably less than that described by the author, particularly where there are a large number of stations on the line.

The writer had occasion a few years ago to devise a protective system for a telephone line operated in connection with a 65-mile, 44,000-volt, three-phase transmission system. This was a single line with the telephone wires carried on the same poles, about 5 ft. below the bottom power wires. The power wires are given a complete transposition between successive load points and the telephone line is transposed at every sixth pole. The system operates without a grounded neutral. Under normal conditions there is no measurable voltage between the telephone line and ground, and the talking qualities of the line are very satisfactory. Measurements were made with one of the power wires grounded, using a voltmeter and potential transformer, and it was found that at normal line voltage, under these conditions, there would be a difference of potential of about 10,000 volts between the telephone wires and ground. An ammeter connected between the two telephone wires and ground showed that there were about 5 amperes flowing. Suitable reactance coils and protective apparatus, arranged as shown in Fig. 1, were installed at two points on the line, and the same tests repeated. It was then found that with normal voltage on the line, and one of the power wires grounded, the voltage on the telephone line was only 14 volts. The telephones could be used very satisfactorily under these conditions, and there was no evidence of any disturbing earth currents flowing between the two reactance coils.



ARRANGEMENT AT STATIONS HAVING REACTANCE COIL

ARRANGEMENT AT OTHER STATIONS

Fig.1

A. W. Copley (by letter): The question brought up by Mr. Taylor as to whether the self-induction of a circuit consisting of a trolley wire with a wire return would be greater than with rail and earth return, is easily settled. A circuit made up of a 4/0 trolley wire with 100-lb. rail return has constants as follows for a 25-cycle, single-track road:

* Resistance volts for 100 amperes per mile,

Trolley	26
Rail	3
Total	29

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* Proceedings A. I. E. E., December, 1908, p. 1733.

Reactance volts per 100 amperes per mile,	
Trolley wire (internal)	1.3
Rails	1.5
Due to field between trolley wire, and return circuit	44.2
Total	47
Impedance—total	55.3

In order to obtain the same reactance with wire return the trolley and return wire must be separated by a distance x determined by the formula:

Reactance volts per mile per 100 amperes $= 5.28 \times 1.92 \log x/0.78$ radius of wire.

This formula holds true when the return wire is of the same size as the trolley wire. It includes not only the reactance due to the field between the wires but also that due to the field inside the wires, hence it represents the total reactance of the circuit.

The radius of the 4/0 wire is 0.20 ft. On placing the reactance equal to 47, and solving the equation for x, the result is 1.6 ft. In other words, the reactance of a circuit consisting of the trolley wire and a return wire at a distance of 1.6 ft. is 47 volts per mile, which is equal to the reactance of the normal circuit consisting of the trolley wire and the ordinary track return.

It is obvious that a greater separation between the wires would cause an increased reactance, consequently Mr. Scott is correct in asserting that a separation of 2 ft. between the wires would cause a greater reactance than that of the normal circuit with track return.

It may be further noted that the resistance drop for the circuit with the 4/0 return is 52 volts per 100 amperes per mile, instead of 29 volts with the normal conditions using the track return. It follows, therefore, that the overhead return circuit will probably involve increased inductance, increased cost of copper, and an increased resistance loss, unless a very large amount of copper is installed.

The reason that the reactances of the trolley-track circuit is low is on account of the large effective diameter of the return circuit. The radius of the conductor does not enter, however, into the formula for obtaining the voltage induced in an entirely separate circuit, such as a telegraph line and its return, this voltage being proportional to the logarithm of the ratio of the distances from the telegraph line of the trolley and its return circuit. Hence the voltage induced in the telegraph circuit is dependent upon the effective depth of the current in the earth.

Frank F. Fowle (by letter): It has long been clearly understood that an electric circuit transmits energy, not through the body of its conductors, except to an almost negligible extent, but through the dielectric surrounding the circuit. The conductors are but a guide for the energy in its course of transmission through the dielectric. The extent of surrounding dielectric which is energized is also known to depend upon the geometric disposition of the conductors in a plane perpendicular to the circuit. The more widely the conductors are separated, in this plane—voltage, power, and frequency remaining constant—the more extensive becomes the body of energized dielectric.

Theoretically the dielectric is energized, in a direction transverse to the circuit, to an infinite distance; but the dielectric stresses diminish at increasing distances from the circuit in a much faster ratio than the distance. The respective intensities of the electric and magnetic fields are expressed, for any given point, by logarithmic functions of the distances from the point to the wires of the circuit, in a perpendicular plane. When the point is at a great distance from the circuit compared with the distances between the conductors composing the circuit, the field intensities become very small and diminish indefinitely as the point moves away from the circuit.

The phenomenon of induction occurs when a second circuit is placed in parallel relation with the energized circuit, at such a perpendicular distance from it that the field intensities have appreciable values. The second circuit will then have upon it electromagnetically induced electromotive forces and electrostatically induced charges. The second circuit will absorb a portion of the energy of the first circuit, derived from the dielectric through which it is transmitted.

By reason of the fact that telephone and telegraph systems operate with low voltage and low power, with sensitive apparatus, they are exceedingly subject to interferences from systems of high voltage and high power. The phenomenon of induction between such systems is, it is true, a mutual one, and telephone and telegraph systems induce disturbances in power systems. But the disturbance to the latter is infinitesimal, for two reasons: first, the initial energy in telephone and telegraph systems is relatively weak of itself; and, secondly, the extremely weak induction in the power circuit virtually vanishes in comparison with the initial energy in the power system.

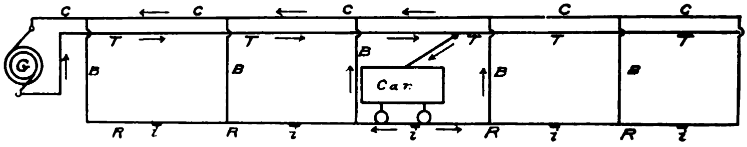
When telephone and telegraph systems exist in parallel proximity to high-voltage, high-power systems, then there is usually interference with the telephone and telegraph systems. This interference varies in degree with the distance between the systems, with the voltage, current, and frequency of the power system, with the geometrical configuration of the power circuit, with the presence of harmonics in the voltage wave and the current wave in the power circuit, with the existence of normal or abnormal grounds on the power system or on the telephone system, with the use of metallic or ground return circuits in the telephone and telegraph systems, and with the system of transposition employed in any or all of the systems.

The problems or difficulties which such a situation presents have two aspects; one of these is the legal aspect and the other is the technical or engineering aspect. Both are of great interest to the engineer. The legal problem, stripped of all details, appears to be one of ownership or right of use of the ether. When a telephone system parallels a power system at a distance of, say, 50 ft. and both systems hold secure legal titles to separate, but adjoining, physical rights-of-way, the inquiry is whether the power system is trespassing in a legal sense, when some of its energy is transmitted through the space over the telephone right-of-way, to the damage and impairment of the operation of the telephone system. Certainly it cannot be held that any one interest or group of interests is entitled to the exclusive use of all the ether. The public requires both transportation and communication, and therefore the public interest requires that this problem be so solved as to harmonize the conflicting interests to the greatest possible degree, without distributing the burden unfairly on either. In the general sense this situation closely resembles the electrolysis problem, where the interests of the street railways and those of municipalities or private companies operating water works are in conflict as to the right of the railway companies to utilize the earth as a return conductor. In the latter case it is undoubtedly a complete preventive of damage to require the railways to use the double-trolley system; and so also it is in the case of the alternating-current systems of traction as regards their disturbance of telephone and telegraph systems. But from the railway point of view a cure so drastic seems unreasonable and burdensome. It remains for engineers to work out, if possible, a solution that will more completely harmonize these opposite interests.

The problem before the engineer naturally divides itself into two lines of investigation, one relating to means of prevention and the other to means of restriction. Mr. Taylor's paper deals with both of these. The means of prevention apply naturally to the railway system, while those of restriction apply to telephone and telegraph systems. Prevention, rather than restriction, is greatly to be desired, if feasible and economical. Fig. 19 and 20 of the paper bring out very clearly some of the means of partial prevention.

The value of a ground-wire, as a means of diminishing the spread of the electrostatic field, is quite important. The following case has come to the writer's attention. A single-phase traction system operating at 3300 volts and 25 cycles, carried on the trolley pole-line a 33,000-volt, 25-cycle, three-phase transmission, a metallic telephone circuit, and a ground-wire erected for the protection of the transmission line from lightning. When the system was put into operation the ground-wire had not been provided with earth connections. It was found that the induced potentials on the telephone line were extremely troublesome and dangerous. But after the ground-wire had been earthed every few poles, the troubles with the telephone line disappeared in large measure, and it became possible to use it, whereas it had been practically impossible before. Of course a potential-neutralizing conductor would theoretically be even better, but it could not then serve the further purpose of a lightning guard.

The writer afterward made a series of observations of the induced potentials in a telephone system, parallel to the traction system just mentioned. He found that the potentials appeared simultaneously with the passage of trains over the traction line, and observed also that there was no potential when there were no trains on the line or when the trains were at standstill. If there had been any electrostatic induction of appreciable magnitude, the observed potential could not have been zero in the absence of trains on the line. These observed potentials were also of a widely fluctuating character, and corresponded generally with the fluctuations of trolley current. There were three trolley sections fed from two sub-stations, the middle section being fed from both ends, and it was observed that the position of the train was a factor in the magnitude of the induced potential. The last mentioned factor was difficult of analysis owing to the varying distance between the traction line and the telephone line.



G = Generator.
T = Trolley Wire.
R = Rail.
C = Return Conductor.
i = Insulating Track Joints.
B = Track Connections To C.

FIG. 1

The electromagnetic field will be greatly restricted by means of a current-neutralizing conductor, as Mr. Taylor says. It is fundamentally necessary for maximum efficiency that the neutralizing conductor be as close to the trolley wire as feasible, and that it carry a current equal to the trolley current in magnitude, but 180 degrees out of phase with it. The writer proposed such a conductor some years ago and endeavored, but unsuccessfully, to have it tried out on a small single-phase road, in 1906.

The features of this arrangement appear in Fig. 1 and 2. The return conductor in this arrangement fulfils largely the functions of a ground-wire as well. The use of sectional track insulators, or insulating rail joints, is proposed in order to diminish the flow of current in the track further than otherwise would occur; the track sections can very conveniently be made to correspond with the lengths of signal blocks, if automatic signals are desired. In the latter case the overhead conductor would be connected to the middle of an inductive track bond, which would be connected in turn between the rails; or only one rail might be used for the propulsion current, reserving the other for signaling purposes.

On account of the impedance drop in the return conductor, there would be some leakage to earth from the rails. The arrangement shown in Fig. 1 is therefore not perfect. Series transformers may be employed to remedy this defect, as shown in Fig. 3. These transformers are arranged with their primaries in series with the trolley wire and their secondaries in series with the return conductor.

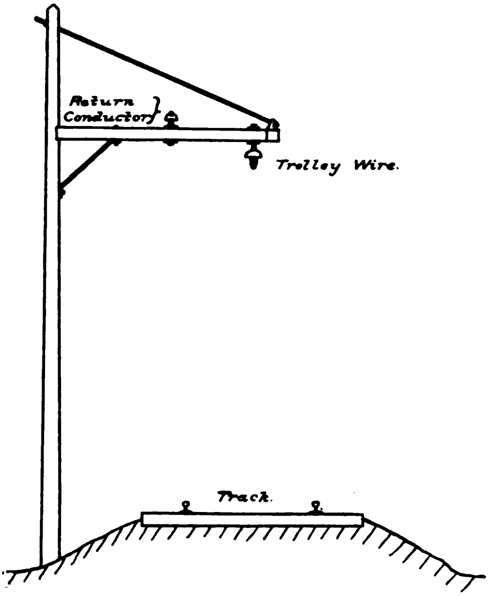


FIG. 2

I cannot agree with Mr. Taylor's statement that these transformers should have a 1:1 ratio. The ratio must be such that with currents of equal magnitude in primary and secondary, but 180 degrees out of phase, the secondary induced electromotive force will just overcome the impedance drop in the return circuit, or such portion of it as corresponds to the section in which the transformer is situated. The ratio will depend, therefore, upon the impedance of the return conductor. The magnitude and phase of the secondary terminal electromotive force may be regulated by means of shunts on the primary or the secondary, or both; and by variation of the primary or secondary turns, and by the latter in combination with the shunts before mentioned.

The means of prevention, as applied to single-phase traction systems, may be summed up as follows:

1. One or more overhead conductors for the purpose of neutralizing or restricting the electromagnetic and electrostatic fields.
2. Means for limiting the flow of current in the track to short sections.
3. Means for maintaining the entire track at zero or earth potential as nearly as possible.

Turning now to means of restriction as applied to the telephone and telegraph systems, there must first be recognized one fundamental difference of great importance between these systems. This is the use of transposed metallic circuits in (the best) telephone practice, and the use of earth return circuits in telegraph practice. Mr. Taylor has shown several metallic circuit schemes for telegraph transmission, but none of these is in general use in this country. Telegraph systems suffer from induction in a far worse degree than telephone systems, because of the use of the earth return. But to require the telegraph companies to convert their systems over to metallic working would be, from their viewpoint, a much more drastic remedy than to compel the traction companies to use the double trolley. The change from grounded working to metallic working in a telegraph line would halve the number of physical circuits and double the investment per circuit mile. The effect which this would have upon rates is obvious; and the final result of such a considerable increase of rates would be a material loss of business, and public inconvenience.

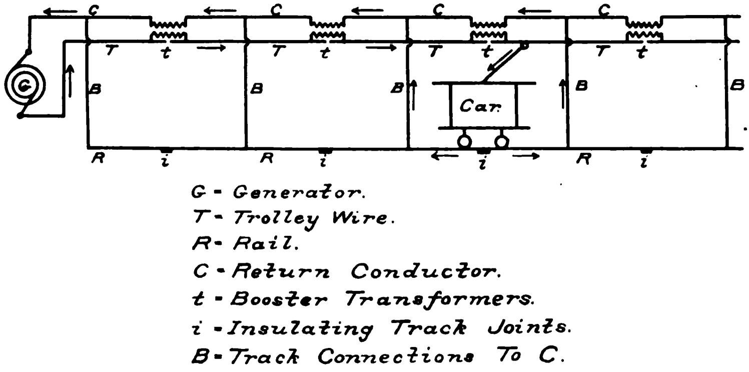


FIG. 3

All telephone and telegraph circuits are separable into two divisions, one overhead and one underground. The overhead circuit is for the great part bare copper and iron wire, carried on pony glass insulators of relatively poor insulating qualities when dirty and wet. The leakage resistance of such circuits varies excessively with the weather. The underground circuit is in cable and possesses properties which remain substantially constant. This difference renders the overhead circuit the most difficult one to remedy.

Circuits in cable have been quite successfully treated in a few instances, by means of compensating transformers. Such circuits are not subject to electrostatic induction because of the enveloping metal sheath, which acts as a shield or electrostatic screen. The magnetic field, however, penetrates this sheath and gives serious trouble.

On overhead bare wire circuits the compensating transformers do not meet all the changing conditions with respect to leakage, but still affords some relief. The practice in regard to line insulators has remained substantially unchanged for many years. The form of insulator in use is well known to be no more than adequate as regards surface leakage, but any improvement in this respect seems to have been prevented by considerations of expense. The arrival of new conditions makes it now very desirable to experiment with improved insulators, with the object of making the line insulation more stable under weather variations. Such an improvement would improve telegraph working in general, particularly quadruplex working. The " common " side of a quadruplex is the first to fail in bad weather, whereas the " polar " or duplex side is very reliable; the failure of the common side is attributable to low insulation. The working of loaded telephone lines is also seriously impaired by low insulation. Here again the use of better insulators will improve the service.

Mr. Taylor mentions the practice of telephone companies in using a frequency of 800 cycles as the average of the general range of telephonic frequencies. A general figure of 750 cycles has been used considerably, because this value gave fair agreement between the results of speech transmission tests over actual lines and the results of calculation from theory. A complete theoretical investigation cannot be made by the use, however, of a single frequency. For practical purposes a range from 100 cycles to 2500 cycles is quite satisfactory, using steps of 100 to 200 cycles.

The point made by Mr. Taylor in reference to the need for more careful attention to electrical balance in telephone instruments and apparatus is very well taken. The necessity for high insulation can be added to this.

I cannot agree with Mr. Taylor's conclusion that grounding the neutral of a three-phase system at one or more places is not of material consequence. The effect of this depends upon the existence of a triple-frequency harmonic in the voltage wave;

where this is not present there will be no change of consequence in the induced disturbance in parallel systems. But where it is present there will be a serious increase, due to the fact that the resultant vector of three such harmonics is a single wave which tends to elevate the potential of the whole system above the earth, and if the neutral is grounded at two or more places, earth currents of triple frequency will result. This phenomenon has been observed and reported, so that the possible effect of grounding the neutral cannot be ignored. Considering electromotive force and current waves of equal amplitude, their effect by induction upon parallel systems will increase with their frequency, so that a triple harmonic may have a considerable effect although its magnitude may be quite small compared with the fundamental wave.

The formulas given by Mr. Taylor for two-wire metallic circuits are, as he says, those commonly given, but do not take into account the presence of the earth. The effect of the earth is given in the following formula,

$$C = \frac{0.07768}{2\log_{10}\left(\frac{4h^2d^2}{m^2(4h^2+d^2)}\right)} \tag{1}$$

where m is the conductor radius, d the conductor separation, and h the altitude above the earth. This formula is deduced from the theory of images. It may be put in the form

$$C = \frac{0.07768}{2\log_{10}\left[\left(\frac{d^2}{m^2}\right)\left(\frac{\frac{4h^2}{d^2}}{1+\frac{4h^2}{d^2}}\right)\right]} \tag{2}$$

The factor $\left(\frac{\frac{4h^2}{d^2}}{1+\frac{4h^2}{d^2}}\right)$ expresses the effect of the earth, and this is very much less than 0.1 per cent when $\frac{2h}{d}$ has ordinary values in practice. The circuit must approach within a very few feet of the earth before there is any appreciable effect. The same is true of the formula for inductance. It should be stated that these formulas all apply to balanced circuits only, or the condition that at any instant the algebraic sum of the wire potentials is zero and the algebraic sum of the currents is zero. The theory underlying the deduction of all these formulas has been given by Maxwell and Heaviside. The latter has deduced many of the formulas and discussed them in his "*Electrical Papers.*"

The theory of images presumes that the earth is a perfectly conducting body of infinite extent, but it is of course well known that this assumption is not borne out. In fact, the vagaries of earth conductivity have long been troublesome and perplexing. This does not of itself destroy the value of the method of images, but it requires a very careful consideration of the effect of the earth's resistivity upon the distribution of earth-return currents. Instead of a true image we find a distorted image, with its centre far below the centre of the true image. The consequent effect is an increase of the inductive phenomena. Much of the experimental work that has been carried on in the field, in connection with the New Haven electrification, must throw a good deal of light on the real character of the image, and it is to be hoped that we may have the benefit of those researches.

Mr. Taylor contends that an ideal metallic circuit is operative, in theory, in a foreign field of any strength. It is true that such a circuit may, by great care and labor, be perfectly insulated and balanced in a strong foreign field, so that it may operate. But under such conditions it possesses a serious defect; it is like a mass in unstable equilibrium. The slightest leak or unbalance throws it out of service, and moreover it cannot be connected or switched to another circuit whose insulation or balance is not high. Besides this, there is the possibility that the circuit as a whole may be elevated in potential, above the earth, to a dangerous degree; if its potential above earth is sufficient, the arresters will discharge continuously. For instance, an exposure, at 30 ft. distance, 20 ft. above the earth, to single-phase trolley conductors carrying 1000 amperes at 25 cycles, for a linear exposure of 30 miles, would keep the ordinary telephone protector in continuous arc until the fuses act. The arresters in these protectors are commonly set for about 350 volts. This potential between line and earth would give painful shocks to persons using the line, should they accidentally place themselves in its path; and it would be certain to shock linemen, and other employes. It seems to the writer, therefore, that Mr. Taylor's contention in this matter is not well founded.

J. B. Taylor: Mr. Scott referred to the fact that the tests on the New Haven road showed no disturbance due to electrostatic induction, and he attributed it to the number of telegraph circuits on the pole line. With this conclusion I agree. Another case where the trolley voltage was the same and the separation of circuits similar, electrostatic induction was felt; but in that case the line instead of carrying twenty or thirty wires, carried only three or four. In other words, the combined capacity of the twenty wires takes up the charging current with a small portion of it on each wire.

Mr. Scott has characterized some of the diagrams as theoretical rather than practical. With that I agree, too. However, one that he picked out (the return conductor with current transformers to prevent return of current by rails and earth) is actually installed in England to meet Board of Trade limitations on difference of potential between points on the rails.

Mr. Copley's tests on allowable induced voltage on telegraph circuits, including simplex, duplex, and quadruplex, are valuable, and their publication, as well as publication of values from tests showing division of current between rail and earth, should be appreciated by all who may be asked to forecast or solve similar problems.

The discussion of relative importance of railways, telegraph and telephone systems, by Mr. Murray, with comparison of electric locomotive records and steam locomotive records and the doctrine of " the survival of the fittest ", opens up interesting questions many of which are outside of the scope of my paper under discussion.

Mr. Murray has taken exception to one or two statements in my summary, to which I will reply as follows:

A circuit so installed that it can be touched by one standing on the ground could hardly be classed as " ideal." However, it may be well that he has called attention again to the fact that a quiet telephone circuit may possess a disagreeable or dangerous potential to earth. Regarding his question if the compensating transformer does not provide complete compensation for voltage in the telegraph wire. I must say that the compensation is not *complete* on account of disturbing factors such as earth currents, resistance losses, differences of wave-shape, phase, etc. The compensation may be effecive for certain line and instrument conditions, but not sufficiently complete to be effective for more sensitive systems. With the compensating transformer as with the general problem, it is all a question of relation between final resulting disturbance and sensibility of apparatus.

J. B. Taylor (by letter): I shall have to agree with Mr. Scott's statement that the self-induction of a circuit of two wires separated by 2 ft. is nearly the same as that of a circuit consisting of one 4/0 wire 20 ft. from the earth, if in the calculation the earth is regarded as being a conductor say 400 ft. in diameter with its center 220 ft. from the 4/0 wire. Hence, Mr. Scott seems to be justified in his objection to my general statement applying to diagram *B* of Fig. 20, that a boosted return circuit " will have small self-induction as compared with the usual single-phase circuit, with overhead conductor and earth return."

Mr. Copley's later contribution to the discussion gives observed values on inductance of trolley wire with earth return, which are in agreement with the above. More properly I might say that the observed values of self- and mutual-induction give us the knowledge of current distribution in the earth justifying the assumption of such a figure as 400 ft. an equivalent diameter of the (earth) return conductor.

Mr. Copley I think has misunderstood my discussion of the effective position of return current with a single-phase railway. I did not state that " part of the return current would be found in the rails and a part at the image of the trolley wire " but that " the image assumption may also lead to too small inductive values on account of the imperfect conductivity of the earth. " I believe that a smaller value than 200 ft. below the surface of the earth, (that is, ten times the depth of the image) will be found as effective position of return current on single-phase roads of less length than the New Haven, or on roads where the trolley voltage is less and sub-stations at fairly short intervals are necessary.

Dr. Steinmetz objects to my statement that the grounded neutral on a three-phase system is not a likely source of trouble to telephone or telegraph systems, and a contribution from Mr. Fowle also takes up this point. At present I know of one system where slight 75-cycle disturbance is felt on telegraph lines as result of exposure to a 25-cycle, three-phase system with neutral grounded at both generating and receiving points. Some of the transformer magnetizing current at triple frequency returns by earth and is responsible for this slight disturbance. I still feel that with generators of average wave shape and transformers worked at not too high density, the troubles from grounded neutral are small as compared with other possible sources of disturbance.

Mr. Nicholson's contribution gives interesting experience on a long line transmitting large amounts of power. The unusual form of transposition which he describes as having come about through successive changes brings out the fact that the mutual induction between circuits, the planes of whose wires are at right angles, may be zero for certain relative locations.

Mr. Cook discusses the relative advantages from the standpoint of safety of telephone lines grounded at the center point of reactive coils versus the use of the insulating transformers. The telephone line with neutral grounded, is, as Mr. Cook claims, more comfortable to handle, but from the standpoint of safety I believe that too much reliance should not be placed on such a system. The telephone line may be broken or open between the grounded points and the person handling same, so that it seems wise in either case to ground a telephone circuit which is likely to be dangerously charged whenever it is necessary to handle same. The practice in this respect should be similar to the best practice on high-tension lines themselves. The risk from handling such a telephone line is reduced as the number of grounded coils is increased, but this involves increased difficulty in maintaining the line quiet; and I have found many telephone lines which were not sufficiently well balanced to be quiet after such grounded coils were installed, no matter how carefully the coils themselves might be balanced. Grounding the telephone line at more than one point also gives opportunity for earth currents and induced currents of large magnitude to pass over the line, and resistance at joints or unequal resistance of the two sides of the line makes the line noisy with the comparatively large currents flowing.

Regarding Mr. Fowle's suggestion that transformers causing return current to flow in a supplementary conductor should have a ratio other than 1:1, the following considerations seem to apply.

The impedance of the return circuit determines the voltage at which the boosting transformer operates, and with a 1:1 transformer practically the same voltage will be found at the primary terminals as at the secondary terminals. If the ratio is other than 1:1, primary and secondary voltages will stand in the ratio of the numbers of turns and the currents in the two windings will be in an inverse ratio. Since the transformer must be magnetized sufficiently to produce the required voltage there will be some magnetizing current in the primary circuit not found in the secondary. This magnetizing current in a properly designed transformer is a small percentage of the total current, but since this magnetizing current is found in one winding and not in the other it must be returned by way of the earth. In other words, such transformers operate, not as the common transformer at constant voltage and magnetic density, but as series transformers at variable voltage and variable density, depending on the amount of load and impedance of the secondary circuit.

I agree with Mr. Fowle that it would be extremely hazardous to attempt telephone service over a typical 30-mile line at 30 ft. distance from a wire carrying 1000 amperes, 25 cycles, with earth return. I have made no contention that operation in such an extreme case is practicable or even possible with present apparatus and general methods of construction. However, I see no reason to modify my statement that *theoretically* a metallic circuit is operative in fields of any strength and practically can be operated in fields too strong to permit usual telegraphic operation with ground return.